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Tailings study operations plan for the streambank tailings and revegetation study

SILVER BOW CREEK INVESTIGATION

TAILINGS STUDY OPERATIONS PLAN
for the
STREAMBANK TAILINGS AND REVEGETATION STUDY

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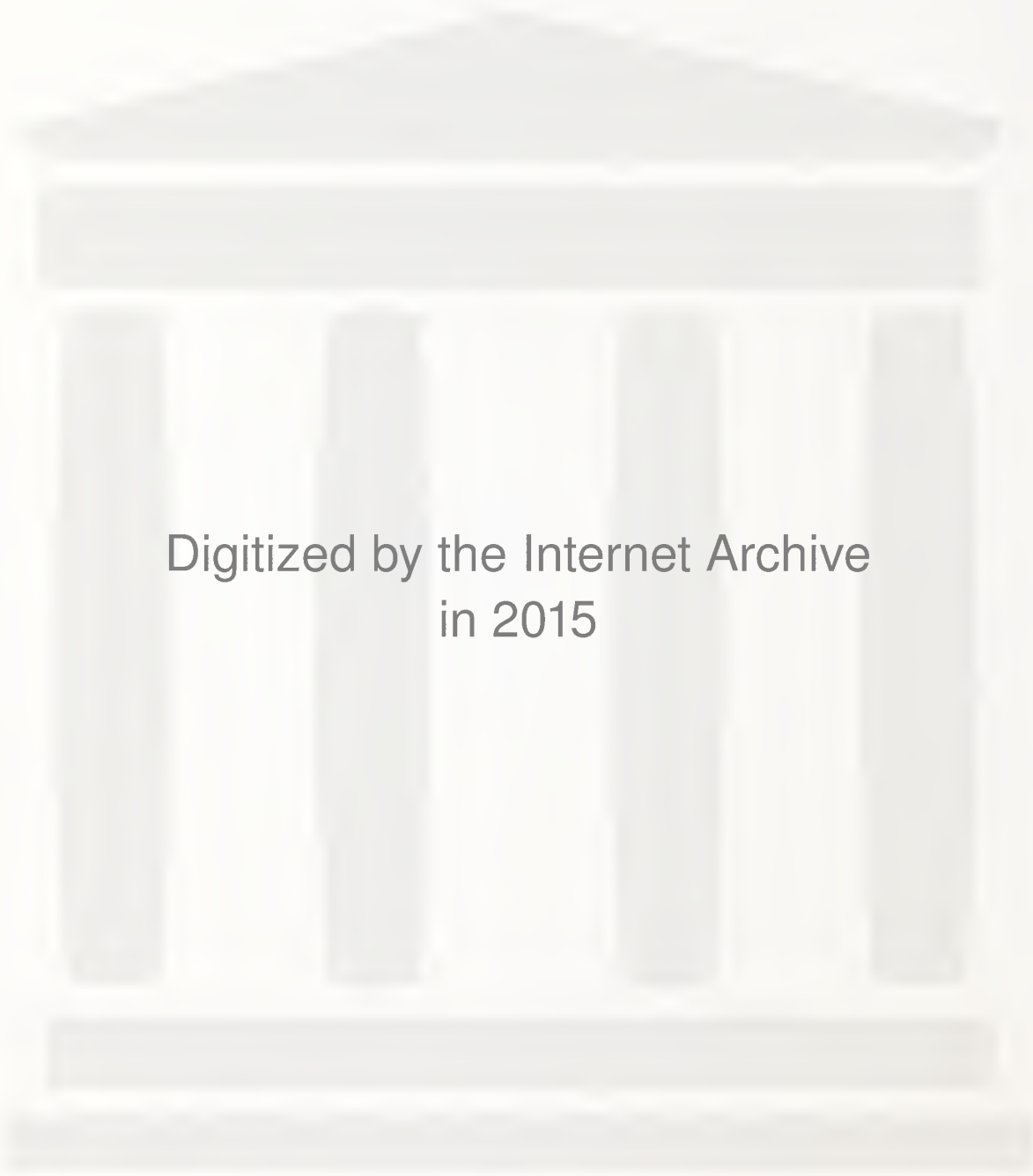
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LIST OF ACRONYMS

ARAR's	Applicable, and Relevant or Appropriate Requirements
CERCLA	Comprehensive Environmental Response Compensation and Liability Act
CLP	Contract Laboratory Program (EPA's)
EPA	U.S. Environmental Protection Agency
FS	Feasibility Study
GSOP	Greenhouse Study Operations Plan
ITR	Inorganic Traffic Report
LAP	Laboratory Analytical Protocol
LRPS	Leachate Reduction Pilot Study
MDHES	Montana Department of Health and Environmental Sciences
NBS	National Bureau of Standards
NPL	National Priorities List
QA/QC	Quality Assurance/Quality Control
QAM	Quality Assurance Manager

QAPP	Quality Assurance Project Plan
RAS	Routine Analytical Services
RI	Remedial Investigation
SARA	Superfund Amendments and Reauthorization Act
SAS	Special Analytical Services
SBC	Silver Bow Creek
SMO	Special Management Office (EPA's)
SOP	Standard Operating Procedure
STARS	Streambank Tailings and Revegetation Study
TSOP	Tailings Study Operations Plan

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CONTENTS

Page

TITLE i
FINAL DISTRIBUTION LIST ii
LIST OF ACRONYMS iii
CONTACT INFORMATION v
CONTENTS vii
LIST OF TABLES ix
LIST OF FIGURES x

1.0 INTRODUCTION 1

1.1 Background 1
1.2 Purpose and Scope 2
1.3 Objectives of STARS 2
1.4 Project Approach 3
1.5 Success Criteria 4

2.0 SCOPE OF STARS TSOP 6

2.1 Task 6 : Mine Waste Sampling and Ranking 7
2.1.1 Analytical Data Review 8
2.1.2 Preliminary sample collection/analysis 11
2.1.3 Review of preliminary sample data 14
2.1.4 Amendment procurement 15
2.1.5 Field mine waste assessment 16
2.1.6 Development of mine waste ranking criteria . . . 19
2.2 Task 7 : Column study 20
2.2.1 Preliminary column studies 20
2.2.2 Column studies 37
2.3 Task 8 : Review of isolation/incorporation techniques 39
2.4 Task 9 : LRPS field work 40

CONTENTS (continued)

3.0 QUALITY ASSURANCE 42

3.1 Overview 42
3.2 Enforcement Aspects 43
3.3 QA/QC Objectives 44
3.4 Quality Control. 44

4.0 SAMPLING AND MEASUREMENTS 47
4.1 Overview of sampling and monitoring 47
4.2 Equipment 48
4.3 Health and Safety 51

5.0 PROJECT PERSONNEL 52

6.0 LITERATURE CITED 53

APPENDIX A : Standard Operating Procedures 55
APPENDIX B : Standard forms 110
APPENDIX C : Equipment Instructions 124

LIST OF TABLES

Table	Description	Page
2.1	Summary of chemical and physical properties of sample S111 from near SBC.	24
2.2	Results of preliminary column investigations comparing CARWA to TEMPE with no amendments . .	25-26
2.3	Results of preliminary column investigations comparing CARWA to TEMPE with lime amendments .	32-35
3.1	QA/QC considerations for the Silver Bow Creek RI/FS STARS	42-43
3.2	Generalized QA/QC steps for soil and leachate samples	45
3.3	Generalized QA/QC steps for field measurements.	46
4.1	Summary of samples to be submitted to a laboratory from the STARS	47
4.2	Monitoring, sampling, and safety equipment list for the Silver Bow Creek STARS - TSOP	48-50

LIST OF FIGURES

Figure	Description	Page
2.1	The upper reach of the Silver Bow Creek CERCLA study area	18
2.2	Extract pH and EC from CARWA and TEMPE cells for two extraction cycle lengths	28
2.3	Cumulative release of copper and zinc from the CARWA and TEMPE apparatus for two extraction cycle lengths	28
2.4	Cumulative release of manganese and lead from the CARWA and TEMPE apparatus for two extraction cycle lengths	29
2.5	Extract pH and EC for lime-amended CARWA and TEMPE cells	36
2.6	Cumulative copper released from the lime-amended CARWA and TEMPE cells	36
2.7	Cumulative zinc released from the lime-amended CARWA and TEMPE cells	37
2.8	Cumulative manganese released from the lime-amended CARWA and TEMPE cells	37

1.0 INTRODUCTION

1.1 Background

The Silver Bow Creek CERCLA Study Area is an extensive inorganic contamination site, located between Butte, Montana and the Warm Springs treatment ponds near Warm Springs, Montana. Contamination of the Silver Bow Creek drainage consists primarily of heavy metals, arsenic, and acid-producing sulfides which pose potentially major health and environmental hazards.

Contamination of air, soil, surface and ground water stems mostly from tailings and other mining waste deposited in the Silver Bow Creek channel and floodplain. Streambank mine wastes in particular are situated so that they may be eroded by wind or water. Soluble metals released from sulfide oxidation may be leached into surface and ground water.

Remedial measures for streambank mine wastes must solve a variety of problems. These include acid production and movement of contaminated leachate to surface and ground water, erosion by water and by wind and direct contact hazard to humans and livestock or wildlife. Typical remedial alternatives which may correct most of these problems include removal to a secure storage area or capping to reduce precipitation infiltration and air entrainment. These techniques work well for sites with small areal involvement or volumes; however, for sites in which the areal extent of contamination is very large and involves large volumes of material the practical application of these technologies decrease significantly. Since streambank mine wastes along Silver Bow Creek are disseminated over much of its 27 mile length, and involve millions of cubic yards of material the Montana Department of Health and Environmental Sciences (MDHES) agreed that new and innovative technologies should be investigated as remedial alternatives. One of these technologies is modification of tailings characteristics (pH, plant-available metals) followed by revegetation.

1.2 Purpose and Scope

The Streambank Tailings and Revegetation Study (STARS) is divided into a laboratory/greenhouse (phase I) component to develop and test treatments at a bench scale, and a field scale (phase II) demonstration of selected remedial alternatives.

The purpose of Phase I of STARS is to develop and test innovative remedial measures which will modify streambank tailings characteristics sufficiently to allow them to be revegetated. Addition of chemical amendments and establishment of vegetation should reduce leachate to ground water, contaminated runoff to surface water, and fugative dust through chemical fixation/neutralization, reduced leachate to ground water due to enhanced evapotranspiration, and surface soil protection by vegetation.

Phase I activities will focus on laboratory development of suitable soil amendments to raise soil pH and reduce plant-available metal concentrations and on greenhouse selection of plant species that can thrive in the amended environment. A detailed asssessment of applicable or relevant, and appropriate requirements (ARARs) will be provided so that contaminant-specific, location-specific, and action-specific clean-up goals are known. Other phase I activities will include development of criteria for characterizing streambank mine wastes on the basis of their chemical and physical characteristics. The goal of this study component is to develop a data base that will allow remediation alternatives to be designed to meet the specific requirements of each mine waste area. It is anticipated that a limited number of "groups" or "types" of mine waste will be identified and that each group or type will have one or more remedial strategies developed for it. The final report of Phase I will include preliminary design of innovative remedial alternatives suited for each waste type.

1.3 Objectives of STARS

The primary objectives of this pilot study are to:

OBJECTIVE 1: Design, field test, and evaluate the response of potential remedial measures for mitigation of human health and environmental impacts from streambank mine wastes using chemical microencapsulation, deep incorporation, cover-soil isolation, and enhanced evapotranspiration techniques.

OBJECTIVE 2: Develop a method of ranking mine waste-contaminated areas for selecting contaminated remedial measures.

These objectives will allow the RI/FS project team to collect the required performance data to design selected innovative remedial alternatives for consideration in the feasibility study.

1.4 Project Approach

The STARS investigation will consist of a Phase I laboratory/greenhouse component followed by a field-scale demonstration of selected remedial alternatives (Phase II).

The level of achievment of the bench-scale remedial alternatives will be compared to established ARARs. A decision to proceed with phase II will be made based on the expected achievement of the clean-up goals and to a degree on the remedial alternative cost.

Phase II activities will include field implementation of the remedial options designed in Phase I and evaluation of the response of the treatments in reducing leachate quantity and in abatement of metal flux to surface and ground water. Phase II activities are not addressed specifically in this tailings study operations plan (TSOP).

The Phase I schedule and the overall project schedule have been designed to allow siting, and construction of demonstration plots so that fall-seeding can be performed in 1988 on the plots.

1.5 Success Criteria

Estimated levels of achievement for the STARS investigation are described below. Some expectation of the effectiveness of the remedial measures to be developed under STARS is necessary to justify development of the remedial alternatives. The success of the STARS effort can be judged in part by the degree to which these success criteria are met in the Phase I investigation, and also by an analysis of how completely the ARARS for streambank mine wastes would be met by the remedial alternatives.

Parameters measured in the column investigation include the metal concentration in leachate, and the residual soil chemistry after adding amendments and leaching 4 to 5 pore volumes of water. Based on preliminininary column investigations and on review of literature, the following reduction in metal concentration in laboratory column leachate can be expected:

Copper, cadmium : >99 percent reduction in metal content
Manganese, iron, zinc, lead : > 90 percent reduction in metal content

Plant availability of metals as measured by extractable metal levels or through plant uptake in the greenhouse study should be reduced substantially. This reduction should result in a sufficient vegetation response so that a significant increase in plant water use would result from the established vegetation.

This level of achievement in the laboratory/greenhouse investigation should scale up into a field demonstration with successful vegetation establishment. Revegetation of streambank waste deposits should reduce leachate quantity to ground water substantially.

Runoff should be decreased due to the amelioritive effect of revegetation on infiltration. Further, surface salt accumulation should be abated, further decreasing metal concentration in surface runoff.

Fugative dust should be substantially reduced (>90%) due to the reduction in near-surface wind velocity brought about by vegetation. Anchoring of soil by roots, and reduced metal concentrations due to soil covering or deep-plowing should further reduce metal in fugative dust.

2.0 SCOPE OF STARS TSOP

A draft work plan has been developed for the STARs project (Schafer and Associates and MSU 1987) addressing the entire investigation. The Tailings Study Operations Plan (TSOP) has been developed to address the tasks relating to collection of mine waste samples and development of ranking criteria, column studies, and preparation of the phase I report including development of remedial design for specific mine waste units. The tasks identified in the work plan are listed below with an asterisk by each task addressed in the TSOP.

Task 1 : Work plan
Task 2 : ARARS
Task 3 : Study Operations Plans (TSOP,GSOP)
Task 4 : QAPP
Task 5 : LAP
* Task 6 : Mine waste sampling/ranking criteria
* Task 7 : Column study
Task 8 : Greenhouse study
* Task 9 : Incorporation/Isolation Techniques
* Task 10: LRPS field work
Task 11: Data validation
Task 12: Data report
Task 13: Draft final report

* - tasks discussed in the TSOP

The work plan for this project has already been submitted (Schafer and Associates and MSU 1987). The ARARs technical memorandum as well as the Greenhouse Study Operations Plan (GSOP, MSU 1987), the Laboratory Analytical Protocol (LAP, MSU and Schafer and Associates 1987), and the Quality Assurance Program Plan (QAPP, MSU and Schafer and Associates 1987) are all to be

submitted along with the TSOP. These documents should be reviewed along with this TSOP to understand the objectives and scope of the entire STARS project. The greenhouse study (Task 8) will be adressed in the GSOP. The data validation process (Task 11) will be described in the QAPP.

2.1 Task 6 : Mine Waste sampling/ranking criteria

This task consists of several components. First, existing analytical data from streambank mine wastes along Silver Bow Creek, from the Butte Hill waste, and from the tailings and aerially-contaminated soils in the Anaconda Smelter site will be reviewed. Next, the characteristics of samples necessary to represent the variety of contaminant types existing in each area will be described and sample points (inferred from the existing data-bases) selected. Next, bulk samples will be collected in the field and submitted for analysis. Samples found to be most representative of the Silver Bow Creek site will be selected for column/greenhouse studies. If additional samples are needed to represent contaminant types in the other CERCLA areas reviewed (Butte Hill and Anaconda Smelter), a technical memo outlining the expected number of additional samples and additional costs required to collect and run these samples will be prepared and submitted.

While soil samples are being collected, samples of possible soil amendments that would be commercially available in quantity for use on these CERCLA sites will be collected and analysed for purity and other key parameters.

Concurrent with the collection of bulk samples, field assessment of other key mine waste parameters needed to design potential remedial measures will be conducted. Important field measurements include depth of mine waste, depth to water table, and hydraulic properties of the unsaturated mine waste.

Finally, a system of ranking mine waste will be developed in the form of a simple diagnostic key. The ranking key will allow wastes to be placed into one of several generic "groups" or "types" of waste each of which will have a

particular remedial measure designed for it.

2.1.1 Analytical data review

Existing analytical data from streambank mine wastes along Silver Bow Creek, from the Butte Hill wastes, and from the tailings and aerially-contaminated soils in the Anaconda Smelter site will be collected and placed into a data-base management system. Variables will be tested for normality, transformed if necessary, and histograms and summary statistics generated. These descriptive data about the population of waste materials will be used to insure that representative samples of all wastes are selected for column and greenhouse studies. If sufficient numbers of comparable data can be assembled, then multivariate grouping statistical analyses (principal component analysis, cluster analysis, discriminant analysis) (Webster 1977, Norris, Berg 1980) will be performed to numerically group waste and tailings types.

Due to the variation in parameters available for review in each data base, a minimum data set of key parameters for use in screening data was chosen.

Previous statistical analysis of mine waste data along Silver Bow Creek has shown that pH and electrical conductivity (EC) are both correlated with soluble metals (Multitech 1986). Either parameter alone is usually insufficient to predict soluble metal levels. Sulfate sulfur oftens correlates with metal level while total or pyritic S is the best parameter for predicting potential long-term acid-production. Soil texture (as percent sand) correlates with pH ($r=-.41$), EC ($r=-.42$), and pyritic sulfur ($r=.39$) in streambank mine wastes (unpublished data SBC RI) and also affects revegetation response due to its effect on plant-water availability. As a result of these findings, the minimum set of mine waste parameters neccessary to screen existing data should include the following parameters:

paste pH
Electrical Conductivity (EC)

Total or pyritic S or S forms
Soil texture

Heavy metal levels (total, extractable, or soluble) will also be assessed where available. However, extractions used for metals are so variable that little can be consistently concluded by comparing different data bases. Relationships between extractable or total metals and the key parameters listed above will be developed by multivariate statistical analysis of individual data-bases.

Data sources to be reviewed include those with analysis of the minimum parameter set. These data sources include:

Silver Bow Creek

Hydrometrics (1983) volume VI: Silver Bow Creek report to Anaconda Minerals (35 mine waste samples at 17 sites)

Multitech (1986) Silver Bow Creek RI report, Appendix B: Ground Water and Tailings Investigation (46 mine waste samples, 47 buried soils and agricultural lands samples, 3 surface salt samples)

Butte Hill

Hydrometrics (1983) volume V: Colorado Tailings report to Anaconda Minerals (4 mine waste samples at 3 sites)

Hydrometrics (1983) volume III: Butte metro area waste dumps report to Anaconda Minerals (15 samples at 13 sites)

Hydrometrics (1983) volume II: Butte Operations report to Anaconda Minerals (12 samples of leach pads, waste dumps, tailings)

Hydrometrics (1983) volume IV: Clark Tailings report to Anaconda Minerals (2 tailings samples at two locations)

Hydrometrics (1984) report to AML Bureau - MDSL on the Butte Hill area (13 samples at 123 sites, no total S data)

Ecology and Environment (1987) Data package for the Walkerville soil sampling project (611 samples including below waste dumps, waste dumps, yards, and drainage; no EC, total S data)

Anaconda Smelter

Hydrometrics (1983) volume VIII: Opportunity Ponds report to Anaconda Minerals (47 samples of the Opportunity Ponds)

Hydrometrics (1983) volume IX: Old Works report to Anaconda Minerals (30 samples of the Old Works tailings)

TetraTech (1985) Summary of Available Soils Data: Mill Creek, MT

TetraTech (1985) Background Arsenic, Cadmium, and Lead Concentrations in Soil, Water, and Air.

TetraTech (1985) Field Operations Plan, MAster Investigation Subtask: Soils.

TetraTech (1985) Field Operations Plan, MAster Investigation Subtask: Soils, Phase II.

TetraTech (1985) Anaconda Smelter RI/FS, Soils Data Report Phase II (data on aerially contaminated soils).

TetraTech (1985) Anaconda Smelter RI/FS, Final, Field Operations Plan, Master Investigation Subtask, Old Works.

TetraTech (1985) Anaconda Smelter RI/FS, Old Works, Data Report

TetraTech (1985) Anaconda Smelter RI/FS, Geochemistry Report (over 200 samples of tailings and buried sediment analyses from 18 boreholes)

TetraTech (1985) Anaconda Smelter RI/FS, Phase I, Data Compilation.

TetraTech (1987) Final Data Report for Solid Matrix Screening Study, Anaconda Smelter Site, Anaconda, MT.

Data from these available sources will be encoded into Dbase III+ for ease in data transformation and output for statistical analysis and graphical display. Key parameters (pH, EC, S data, texture data, metal data) will be transformed as necessary so that data approximate a normal distribution. A statistical summary and frequency distribution (histogram) will be prepared to characterize the population of wastes analysed.

If a sufficent number of samples can be assembled from comparable data-bases, a multivariate principle component analysis will be performed to numerically group samples. The principle component analysis will select those variables (analytical measurements) in a step-wise fashion that are most

useful for "separating" (finding differences among) samples. The cluster analysis and discriminant analysis will be employed with the variables selected in the principle component functions. These techniques provide a grouping of samples. Discriminant analysis provides a means of scoring new samples thus potentially providing a numerical means of grouping samples. If meaningful groups of waste can be delineated using discriminant analysis, then the scores for canonical functions one and two could be used as a means of ranking waste types. This information would be used in the mine waste ranking criteria development subtask.

Based on an assessment of the characteristics of wastes represented in the Silver Bow Creek data-base, selected samples will be chosen which are thought to be representative of the variety of contaminants likely to be encountered on the Silver Bow Creek site. It is expected six generic types of wastes will need to be tested in the column and greenhouse investigation. In order to collect the six most representative samples, 35 candidate samples will be selected for collection and analysis (See section 2.1.2).

If additional types of waste must be collected and analysed to represent the Butte Hill and Anaconda Smelter sites, then a technical memo will be developed outlining the number of additional samples necessary from each site, the approximated desired characteristics of these samples, and the cost to include these additional samples in the phase I of the STARS investigation.

2.1.2 Preliminary sample collection/analysis

Results from the review of existing analytical data will provide a list of up to 35 candidate samples which are to be collected from the Silver Bow Creek site. Sample sites will be selected to satisfy two sampling objectives, 1) provide a representative cross-section of waste "types" identified in the analytical data review, and 2) collect samples distributed throughout the length of the Silver Bow Creek site. Collection of additional samples as needed to represent the Butte Hill and Anaconda Smelter site will be addressed by contract amendment.

In order to collect samples in the field with the proper characteristics, soil pH, EC and texture may have to be determined in the field to locate a potential sample site. The Standard Operating Procedure (SOP-1 through SOP-3, Appendix A) for measuring these parameters on soils in the field are attached. Standard forms for encoding soil pH, EC, and texture are included in Appendix B.

Samples will be collected in sufficient quantity to conduct all requisite column and greenhouse studies on a single mixed, homogeneous sample. Samples will be collected from the upper 15 inches at each sampling point if the materials encountered are relatively homogeneous to 15 inches in depth. If contrasting materials are found at shallower depths, then the sample will be composed from a homogenous layer less than 15 inches thick. Buried sample layers (i.e. natural soil buried by mine waste deposits) will be collected from a 15 inch depth increment, if homogenous. The 15 inch depth increment was selected because this may be the maximum depth to which amendments can be incorporated using deep-incorporation techniques.

Approximately 300 pounds of soil material will be required for column and greenhouse investigations. Large plastic (42 gallon) containers will be used for sample collection and shipment to the Montana State University (MSU) greenhouse facility for drying, mixing, and subsampling. Samples will be maintained under chain-of-custody from the time they are collected in the field. Samples will be collected in a manner believed to prevent significant amounts of cross-contamination. The SOP for soil sample collection and implement decontamination is found in Appendix A (SOP-4).

A soil description will be performed at each soil sample location as described in SOP-5 (Appendix A). Important soil morphological parameters will be described and encoded into a Dbase III+ file that can be later linked with the laboratory chemical and physical data used for statistical analysis. Standard forms for soil site and horizon description are attached in Appendix B.

In the greenhouse, samples will be spread for air-drying on a large plastic sheet. Soil will be mixed periodically to speed drying. Large clods

of sample will be crushed and broken and the sample homogenized mechanically in a mixer. Homogenized sample will be placed in the original plastic containers. Samples to be submitted to the contracted laboratory for chemical analysis will be obtained by taking ten cores from the mixed sample using an Oakfield sampler. The composite soil sample will be placed in I-Chem jars and shipped to the designated laboratory under chain-of-custody. Standard Operating Procedures for inserting QA/QC samples addressed in detail in the QAPP (SOP-6) and for preserving and shipping samples (SOP-7) will be followed. Standard forms for tracking samples and for preserving data integrity are included in Appendix B (Chain-of-custody record, custody seals, inorganic traffic report, special analytical services (SAS) packing list, sample identification matrix, EPA tag, rapid carrier shipping label).

Subsamples obtained and prepared as described above will be analysed for the following parameters:

saturation paste extract

pH
Electrical conductivity (EC)
saturation percentage
B, Ca, Mg, Al, As, Cd, Cr, Cu, Fe, Mn, Na, Pb, Zn

HNO_3/H_2O_2 extractable (CLP total)

Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Pb, Zn

Ammonium Acetate pH 5.5 extractable

Ca, Mg, Al, Cd, Cr, Cu, Fe, K, Mn, Na, Pb, Zn

HCl extractable As
NO_3-N
CEC
Organic matter
Sand, silt, clay, and rock fragment percentage
Modified Acid-Base Account, S forms
SMP buffer lime requirement
Total and extractable P

A description of the specific methods to be used is included in the Laboratory Analytical Protocol (LAP). Analysis of soluble metals is being performed to assess the potential for mine wastes to contaminate surface and ground water. The HNO_3/H_2O_2 extraction provides a measure of the total concentration of metals in the mine wastes. Analysis of the potential plant-available metal fraction is also important. Several extractions have been used to simulate the plant-available fraction of ions in soil. Some extractants like DTPA are better-suited to soils with higher pH levels. The ammonium acetate extraction has been widely used for acid soils as a measure of plant-availability. In addition, prior data are available from the site for ammonium acetate extractable metals.

In addition to the laboratory analyses performed on the bulk samples, field samples will be collected for determination of bulk density, particle density, and water retention. An SOP (SOP-8, Appendix A) is attached for bulk density, particle density and water retention measurements.

2.1.3 Review of preliminary sample data

Results of the analyses performed on the candidate representative bulk samples will be reviewed and six samples chosen for use in the column and greenhouse investigation. It is assumed that six samples will be sufficient to represent the variety of waste types found in the Silver Bow Creek site. The limited number of samples selected for detailed column and greenhouse tests may seem minimal in light of the extreme variability of waste materials observed on-site. The reader is reminded that this investigation is aimed at development of remedial actions which must be scaled up and implemented over areas ranging from 1 to 10 acres or more in size. Much of the inherent variability in waste characteristics would be exhibited within a given 1 to 10 acre parcel. Thus only gross differences in waste characteristics observable between parcels of significant size will be addressed.

Bulk samples not chosen for column and greenhouse portions of the investigation will be disposed of on the Silver Bow creek site.

If more than six samples are necessary to characterize the diversity of wastes found on the Silver Bow Creek site, then a contract amendment to include the additional samples in the investigation will be prepared and submitted to the MDHES.

2.1.4 Amendment procurement and analysis

Amendments to be tested in the column studies fall into several categories. Many amendments will be tested in combination to obtain optimum results. Amendments will include 1) neutralizing agents to reduce acidity, 2) calcium sources which may reduce plant uptake of soluble metals, 3) phosphorus sources which may form insoluble precipitates with metals, and 4) organic amendments that add metal adsorption capacity to the soil system and also provide for long-term release of plant nutrients, and enhance the physical nature of the root zone.

Soil amendments to be used in the column study will be obtained and analysed for purity. A number of commonly-available amendments (agricultural lime, triple-super-phosphate fertilizer) will be obtained from local sources. In addition, local amendments available in sufficient quantity to be used on the site (>50,000 tons) will be analysed. A list of amendments that may be used is included below.

Neutralizing amendment

Agricultural lime - Russ Dougdale (Butte)
Agricultural lime - Big Horn Calcium (Red Lodge)
(a dolomitic and calcitic lime will be evaluated)
Kiln dust - Ash Grove (Helena)
Kiln dust - Trident
Kiln dust - David Heeb (Spokane)
reagent grade Ca(OH)2
flyash - Colstrip, MT
sugar beet processing waste (Billings)

Calcium Sources

gypsum - Hills Materials (Rapid City, SD)

CaCL2 - Dyce Chemical (Billings)

Phosphorus Sources

Triple super-phosphate (0-45-0) AgriBasics

Stauffer waste - flouro-phospho silicate (Rocker, MT)

phospho-gypsum - P fertilizer waste J.R. Simplot (Pocatello, ID)

phosphate ore - (Cominco) Garrison, MT

phosphate processing waste - (Cominco) Garrison, MT

Organic amendments

barnyard manure

sawdust wood waste

paper pulp waste (Missoula)

cereal grain straw

grass hay

Analyses to be conducted on the amendments will vary by amendment but may include total Ca, P, S, Mg, particle-size (sieve) analysis, dry density, or lime equivalence. Metal impurities will not be analysed, but analysis of column leachate should reveal excess leachable elements if present. See the LAP for additional information on the amendment analyses to be performed.

2.1.5 Field mine waste assessment

Several characteristics of waste materials which are important remedial design criteria cannot be measured by laboratory analysis. Depth to the water table influences the potential for ground water contamination and also affects surface salt accumulation. Depth of mine waste will determine the methods or equipment that can be used to incorporate amendments. The hydraulic properties of waste materials (unsaturated hydraulic conductivity, desorption curve) affects water movement patterns and plant-availability of water and is therefore important for designing remedial treatments where sufficient water

must be available for plant growth and where upward solute flux from buried contaminants is to be prevented. Knowledge of the hydraulic conductivity is particularly important where prevention of surface salt accumulation is an element of the remedial design.

At each soil sampling location where bulk samples are collected, the depth of mine waste, pedologic characteristics of waste and buried soil, and depth to ground water will all be measured. A hand-operated soil corer or truck-mounted hydraulic soil probe will be used to observe the depth to the water table to 7 feet. In addition, the condition of the Silver Bow Creek channel banks will be noted. A site map of the Silver Bow Creek CERCLA study area is shown in Figure 2.1. The SOP for soil descriptions (SOP-5, Appendix A) and for soil pH, EC, and texture determination will be followed (SOP-1 through SOP-3). Data will be encoded on standard field forms (Appendix B).

At each site, the soil water characteristic curve which relates water content to water potential will be determined for selected horizons. The soil water characteristic curve will be determined by collecting undisturbed soil cores at selected depths. Cores will be placed in a Tempe Cell (described in Appendix C) and water content measured at 0, -0.1, -0.2, -0.5, and -1.0 bars water potential. Water content at -15 bars of water potential will be measured on a disturbed soil sample. An SOP (SOP-8, Appendix A) has been developed for measuring the soil water content at various water potentials using undisturbed soil cores.

Measurements of unsaturated hydraulic conductivity will be performed in the field. The Guelph permeameter (Soil Moisture Equipment Compant, Santa Barbara, CA) will be used to measure unsaturated hydraulic conductivity. This device is a constant head permeameter which provides a measure of field-saturated hydraulic conductivity, matric potential, and a parameter for predicting unsaturated hydraulic conductivity from field-saturated conductivity. A SOP (SOP-10, Appendix A) has been developed for use of the Guelph permeameter. Information on the instrument is included in Appendix C.

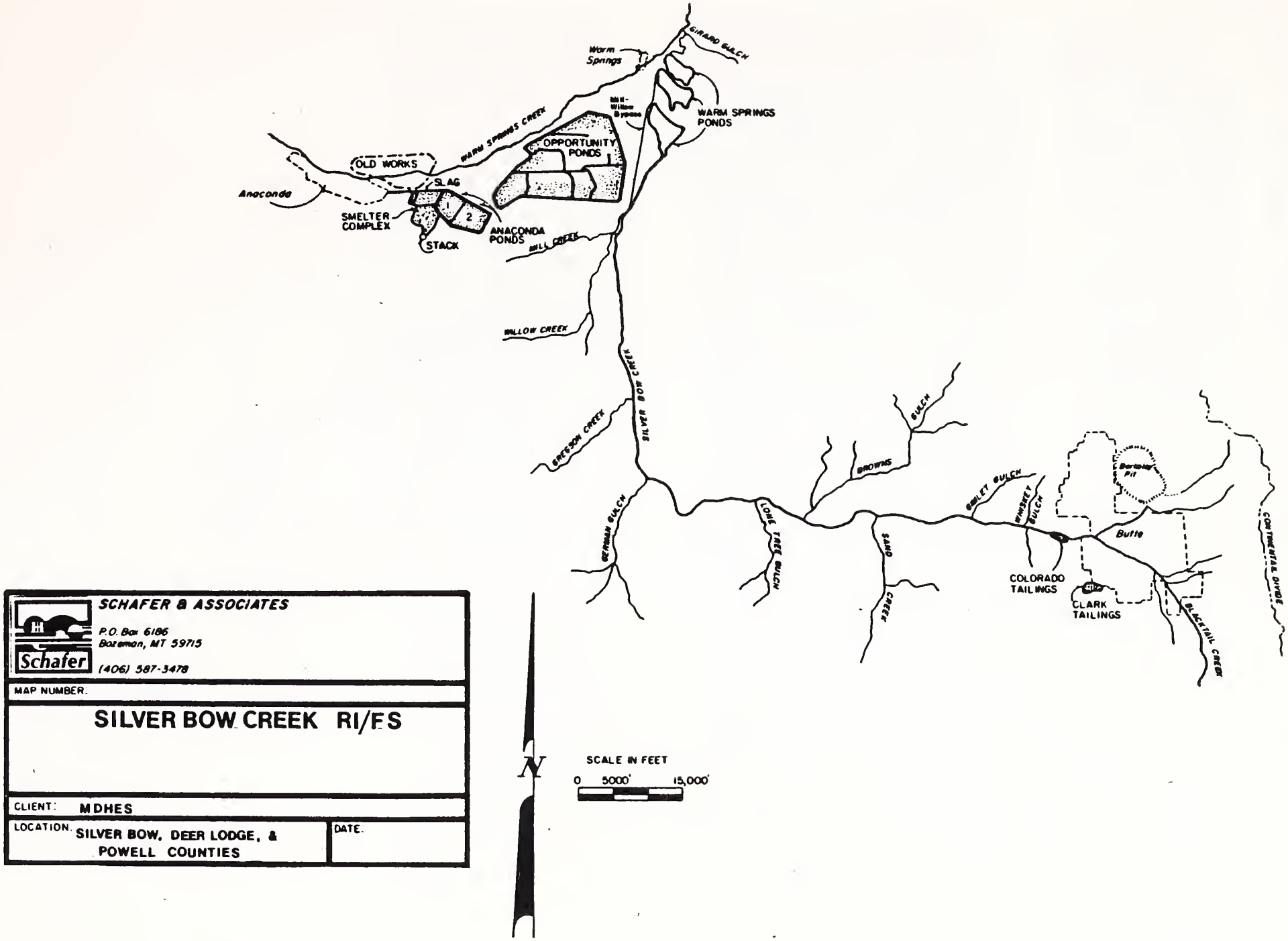

Figure 2.1 The Silver Bow Creek CERCLA study area.

2.1.6 Development of mine waste ranking criteria

The data summary developed during the initial screening of sample locations will be used to develop a key for classifying waste materials based on easily observed field parameters (if possible) into separate groups of waste. Each waste type classified will have one or more remedial alternatives designed for it.

The waste ranking key will be based on pH, EC, texture, S content, mine waste depth, depth to ground water, and one or more additional parameters that could be measured in the field or by an inexpensive lab test (total S, sulfate-S, soluble Cu, etc.). If the numerical grouping of waste materials by discriminant analysis is successful, then waste materials may be scored by graphing their scores on the first two canonical functions developed in the discriminant analysis test. The canonical functions are simple algebraic functions involving two or more parameters. The scores plotted on an X-Y coordinate system would differentiate all samples into definable groups (Norris 1971).

A description of each waste type defined will be developed so that a remedial alternative can be developed for it. Each waste type will have one or more remedial alternatives designed including appropriate soil amendments, procedure for determining amendment rate, means of amendment incorporation, vegetation selection, post-remediation management and land use, and in some cases soil movement requirements, cover-soil and capillary barrier design, drainage requirements, or leaching requirements.

2.2 Task 7 : Column Study

2.2.1 Preliminary Column Studies

The purpose of the column investigation is to screen soil amendments to determine their effectiveness in reducing solubility and plant-availability of heavy metals. Several preliminary column investigations will be conducted to develop a workable procedure expected to provide precise results and to correlate with field response. Criteria outlined below have been used to screen potential column construction and operation design.

The column investigation will be used to screen the effectiveness of a variety of soil amendments at reducing solubility and bioavailability of heavy metals. The columns should be constructed and operated to simulate field conditions. Streambank mine wastes are mostly above the water table, are barren of vegetation, and have a soil water potential of -0.1 to -0.2 bars. The arid regime in the region limits the amount of drainage through the system. As a result, the contaminant concentration during initial leaching production is of importance (0 to 0.5 pore volumes of leachate). However, leaching to remove soluble contaminants may be a component of potential remedial measures. Therefore, the effects of limited continued leaching (2 to 4 pore volumes) must also be observed.

These considerations suggest that the columns should be at least moderately oxidizing with unsaturated conditions most of the time. Leachate should be collected through 2 to 4 pore volumes which is the quantity required to remove 80 to 95 percent of soluble salts (ayers and Westcot 1976). Leachate metal concentrations should be observed in detail during initial leachate production.

Two column apparatus able to fulfill these conditions are readily available. They are the Tempe cells marketed by Soil Moisture Equipment Company (Appendix C), and the Computerized Automated Rapid Weathering Apparatus (CARWA) developed at Montana State University (Appendix C).

Preliminary experiments need to be conducted to refine the column leachate collection procedure and to test the sensitivity of extraction time, column type, column height, amendment equilibration period, and volume of extract. Experiments have been designed to test the effects of these variables. The first two experiments have been completed:

- EXPMT. 1: comparison of CARWA and TEMPE results for variable extraction periods without added amendments
- EXPMT. 2: comparison of CARWA and TEMPE with added CaCO3 or Ca(OH)2
- EXPMT. 3: reaction kinetics of a variety of amendments
- EXPMT. 4: effect of column height on leachate metal concentration
- EXPMT. 5: need for supplemental aeration/mixing in columns

Results from the first two experiments have been used to develop and refine the column extraction procedure. Results are discussed below.

EXPERIMENT 1 : CARWA/TEMPE COMPARISON : NO AMENDMENTS

Objective:

Compare results of CARWA and TEMPE, explain differences if any, and select best column test based on perceived representativeness and ease of use.

Evaluate the effects of varying length of time between extraction cycles and select best extraction time.

Approach:

Both the CARWA apparatus and the TEMPE cells were run through two kinds of extraction cycles consisting of four extractions each. In one set, a short interval was used between extractions (1 hour). In the other set a long interval (2 day) was used.

In each apparatus, 200 grams of soil (sample S111, Table 1) were added and brought to the saturation percentage as indicated by the saturation paste

moisture content (43 percent). Solutions were collected from TEMPE cells by applying 0.2 bars of pressure for 15 minutes. Preliminary tests found that most leachate was obtained within this time period. CARWA was run manually through the agitation (60 minutes), extraction (10 minutes), and dump cycles to obtain samples. Solutions extracted from the TEMPE and CARWA apparatus were measured for volume, ph, and EC if volume was sufficient. Leachate solutions were also analysed for levels of copper, zinc, manganese, and lead. The CARWA apparatus was brought back to volume by saturating with an equivalent amount of distilled water. TEMPE cells were resaturated by bringing them back to their original saturated weight with distilled water.

Solution concentration data, pH and EC measurements were compared to volume of extract released. Solution volume was converted to pore volumes by assuming a soil porosity of 42% (assumes a particle density of 2.65 g/cm3 and a bulk density of 1.5 g/cm3). Although this density may be on the high side, it was a sandy well-sorted mine waste material which would be expected to have a high density. Effluent metals data were transformed to provide cumulative metal released on a soil weight basis using effluent volume and original weight of dry soil added to the columns (200g).

Results:

No extract volumes were available from the CARWA-short method, so volumes were estimated based on volumes recovered from the TEMPE cells. In the CARWA-long method, significant drying apparently occurred during the waiting period. As a result, extract volume was smaller than for the TEMPE method and the actual moisture content at extraction is uncertain. Results of the CARWA and TEMPE extractions are shown in Table 2.

Data from the column extracts from the CARWA and TEMPE cells are plotted in Figure 2.2 through 2.4 showing cumulative changes in pH and EC (Figure 2.2), and release of Cu and Zn (Figure 2.3), and Mn and Pb (Figure 2.4) during the extractions performed. Extract pH seemed to converge for all extraction periods and column types to around 4.1, close to the reported sample pH of 3.7. Soil EC levels appeared to peak near 10, the reported saturation extract

EC, for all methods. Although the relative concentrations of Cu, Zn, and Mn were very similar for each extraction method, the shape of the release curve differed slightly. In general, the CARWA method had higher values at initial extraction volumes (0.2 PV) than the TEMPE method. Cumulative release from 0.2 to 1.0 pore volumes was nearly identical for CARWA-long and TEMPE-long however. The water held in the porous ceramic portion of the TEMPE assembly would account for this offset. Release of approximately 12 to 15 ml of water from the ceramic would cause apparent release of 0.2 PV of relatively clean water observed in TEMPE. Later extraction volumes would displace the water in the ceramic by "piston displacement" accounting for the similarity in results after the first 0.2 PV.

Comparison of the short and long extraction intervals indicates that metal concentration (as well as EC) "tails off" in TEMPE for the long extraction interval. The same appears to be true of CARWA but the reduced sample volume obtained makes it difficult to interpret CARWA results. A possible cause of the reduction in metal release after long extraction periods may be formation of anoxic conditions causing formation of secondary sulfides. The lower solubility of metal sulfides would account for the lower metal release.

Conclusion

TEMPE was easier and less time-consuming to use than CARWA, was easier to decontaminate between samples and would be easier to adapt to running large sample lots simultaneously. Results for both tests were similar if corrections are made for the solution held in the porous ceramic. The short period of extraction appears suitable for simulation of metal release. Oxygen-limiting conditions during the long extraction period may have reduced metal release.

Table 2.1. Summary of chemical and physical properties of sample S111 from near Silver Bow, Silver Bow Creek RI/FS.

		Saturation Extract				
sample	pH	EC mmhos/	saturation (%)	Calcium (meq/l)	Magnesium (meq/l)	Sodium (meq/l)
S111	3.7	10.7	33	17.7	14.2	1.94

TOTAL S	PYRITIC S	SO4 S	TOTAL As	Bray As	Bray P	NO3 N	Mo
			(mg/kg)				
9560	1230	6500	1020	35.5	13.6	0.48	1.48

EXTRACTION	Cu	Zn	Fe	Mn	Cd	Pb
			(mg/kg)			
WATER SOLUBLE	762	587	0.82	624	1.74	<.06
NH4OAC EXTRACT	1300	846	77.3	866	2.84	0.81
HNO3/H2O2 TOTAL	2410	5000	29100	2690	1370	1530

Table 2.2. Results of preliminary column investigation comparing CARWA to TEMPE with no amendments

SAMPLE NAME	VOLUME (ml)	PORE VOLUMES	pH	EC (mmhos/cm)	Copper SOLN. (mg/l)	Copper CUMULATIVE RELEASE (mg/kg-soil)	Zinc SOLN. (mg/l)	Zinc CUMULATIVE RELEASE (mg/kg/soil)
CS-1	18	.2097902			489	44.01	936	84.24
CS-2	18	.4195804	3.94		2350	255.51	2613	319.41
CS-3	18	.6293706	4.1	10.25	1948	430.83	1990	498.51
CS-4	18	.8391608	4.18		2257	633.96	2255	701.46
CL-1	14	.1631702	4.38	9.89	1591	111.37	1785	124.95
CL-2	4.5	.2156177			444	121.36	991	147.2475
CL-3	4.5	.2680653	3.76		1682	159.205	2377	200.73
CL-4	16	.4545455	3.94	9.15	1350	267.205	1512	321.69
TS-1	18.5	.2156177	5.86	3.32	99	9.1575	368	34.04
TS-2	19	.4370629	4.66	10.11	1841	184.0525	1669	192.595
TS-3	21	.6818182	4.3	10.35	1910	384.6025	1675	368.47
TS-4	20	.9149184	4.22	10.35	1841	568.7025	1669	535.37
TL-1	19	.2214452	5.49	3.21	276	26.22	394	37.43
TL-2	19	.4428904	4.2	10.26	1560	174.42	2015	228.855
TL-3	19	.6643357	4.21	9.46	1234	291.65	1530	374.205
TL-4	20	.8974359	4.3	6.56	660	357.65	738	448.005

CS - CARWA short cycle

CL - CARWA long cycle

TS - TEMPE short cycle

TL - TEMPE long cycle

Table 2.2. (continued)

SAMPLE NAME	VOLUME (ml)	PORE VOLUMES	Manganese SOLN. (mg/l)	Manganese CUMULATIVE RELEASE (mg/ kg-soil)	Lead SOLN. (mg/l)	Lead CUMULATIVE RELEASE (mg/ kg/soil)
CS-1	18	.2097902	821	73.89	59.2	5.328
CS-2	18	.4195804	2489	297.9	220	25.128
CS-3	18	.6293706	1962	474.48	194	42.588
CS-4	18	.8391608	2153	668.25	215	61.938
CL-1	14	.1631702	1715	120.05	170	11.9
CL-2	4.5	.2156177	805	138.1625	46.1	12.93725
CL-3	4.5	.2680653	2145	186.425	170	16.76225
CL-4	16	.4545455	1527	308.585	140	27.96225
TS-1	18.5	.2156177	415	38.3875	15.3	1.41525
TS-2	19	.4370629	1699	199.7925	182	18.70525
TS-3	21	.6818182	1748	383.3325	188	38.44525
TS-4	20	.9149184	1723	555.6325	170	55.44525
TL-1	19	.2214452	415	39.425	26.9	2.5555
TL-2	19	.4428904	1650	196.175	158	17.5655
TL-3	19	.6643357	1438	332.785	122	29.1555
TL-4	20	.8974359	919	424.685	68.8	36.0355

CS - CARWA short cycle

CL - CARWA long cycle

TS - TEMPE short cycle

TL - TEMPE long cycle

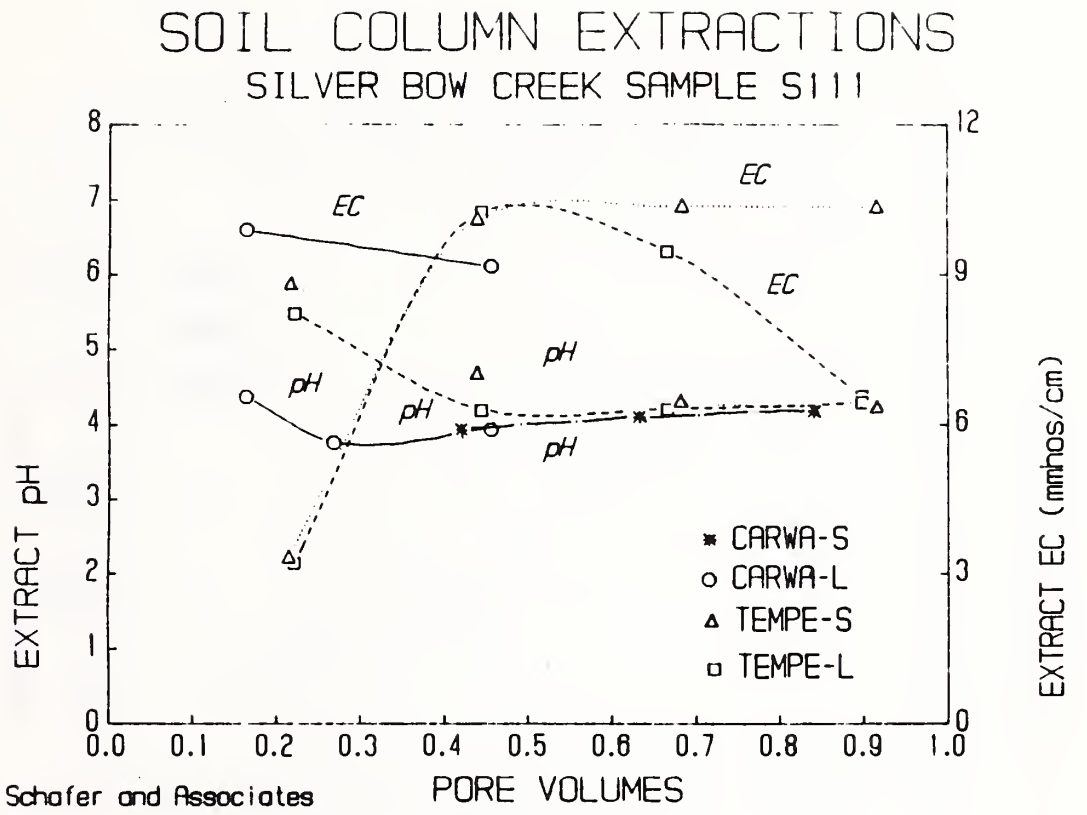

Figure 2.2. Extract pH and EC from CARWA and TEMPE cells for two extraction cycle lengths.

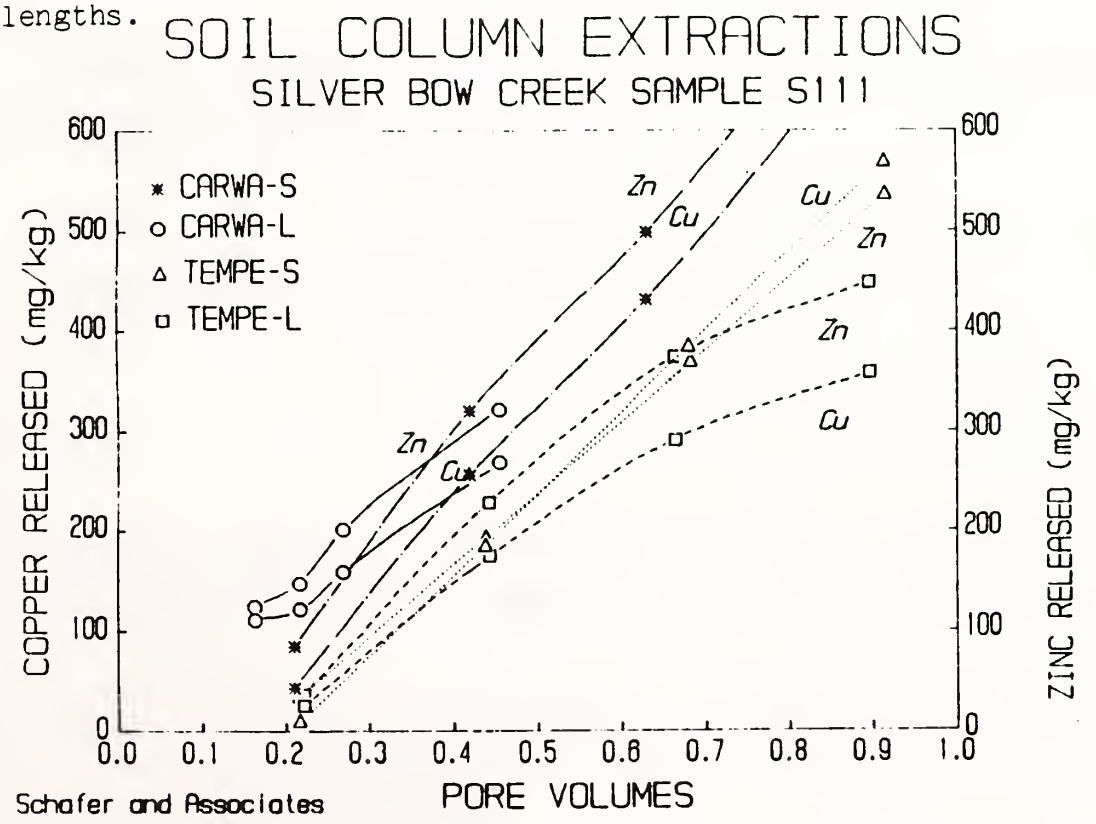

Figure 2.3. Cumulative release of copper and zinc from the CARWA and TEMPE apparatus for two extraction cycle lengths.

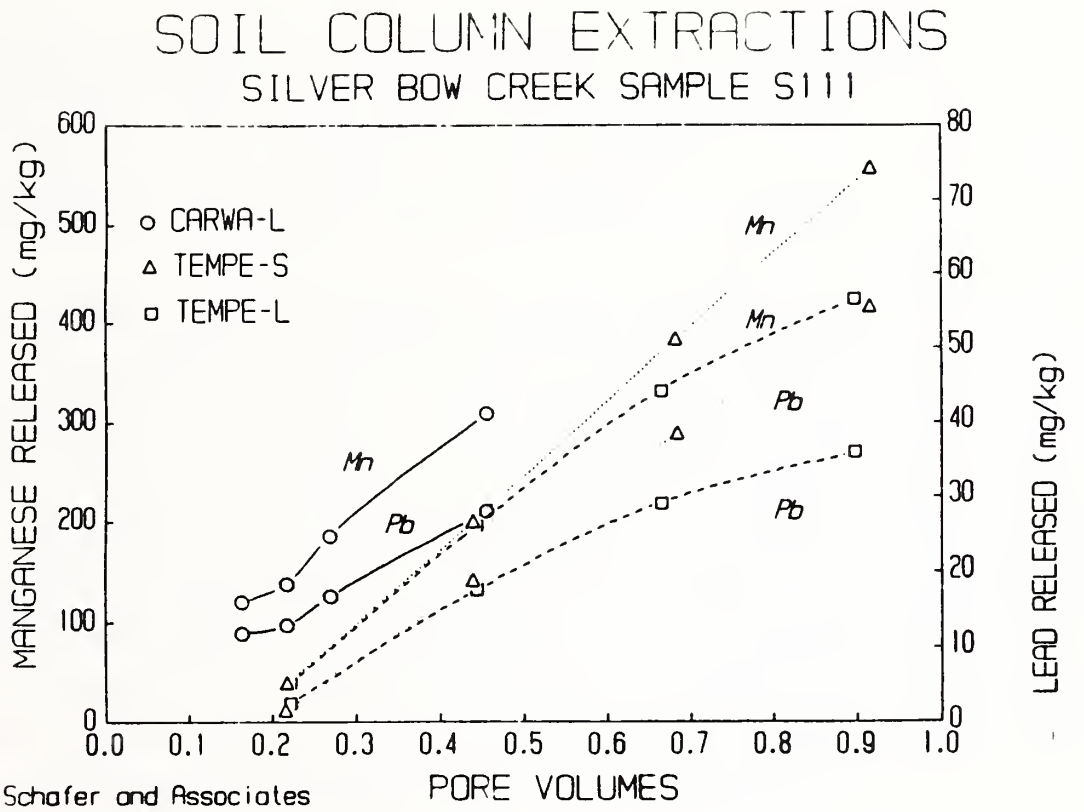

Figure 2.4. Cumulative release of manganese and lead from the CARWA and TEMPE apparatus for two extraction cycle lengths.

EXPERIMENT 2 : CARWA/TEMPE COMPARISON : LIME AMENDMENTS

Objectives:

Compare results of CARWA and TEMPE cells when calcium carbonate and calcium hydroxide amendments are added. Use the short extraction cycle.

Collect leachate over 4 to 5 pore volumes to evaluate if cumulative release of metals remains linear as in the first experiment or if a plateau concentration is reached.

Approach:

The columns were cycled in the same manner as in the first experiment with two exceptions. After the first four extraction cycles, the apparatus was oversaturated so that a larger volume of leachate could be collected rapidly. Secondly, two different lime amendments were added.

Lime rates were calculated based on a modified acid-base account procedure. The potential acidification by sulfide-S as calculated by subtracting sulfate-S from total S. Sulfide-S was multiplied by the stochiometric conversion factor of 31.25 tons/acre calcium carbonate per percent S. The organic S was assumed to be zero. An added lime requirement for active acidity was estimated to be 4 tons per acre. The two components of lime requirement were summed and multiplied by a 1.25 safety factor for a total lime requirement of 16.7 tons per acre. This lime rate yielded 3.34 grams of reagent grade CaCO3 in 200 grams soil and 2.46 grams Ca(OH)2 which has a calcium carbonate equivalence (CCE) of 136 percent.

Amendments were added and mixed into dry soil, then the soil was saturated and cycled through the cells within 1 to 2 hours. Extracts were collected and analysed in the same manner as in experiment 1 except that they were filtered (to remove soil) and acidified (to keep metals in solution). For the TEMPE - CaCO3 samples, samples were filtered and acidified the next day. As a result of this delay, it appeared that an bluish oxide mineral had formed and was removed by filtration which reduced the actual dissolved metal content.

Results:

Results from the second experiment are presented in Table 2.3 and in Figures 2.5 through 2.8. Addition of lime reduced the effluent metal content, increased pH, and decreased salinity dramatically. Significant differences were noted between amendments but less so between column types.

Addition of CaCO3 reduced EC (Figure 2.5) to about 4 mmhos/cm and

initially raised pH to 4 to 4.5. After leaching additional soluble salts from the system (1 pore volume), the salinity stabilized at 2 (equilibrium with $CaSO_4$) and pH rose to near 6 to 6.5. When $Ca(OH)_2$ was added (known to be more reactive, faster-acting), the EC dropped immediately to 2, and pH more quickly achieved levels of 6.5 and higher.

Calcium hydroxide appeared to reduce metal release more effectively than $CaCO_3$. Copper concentration (Figure 2.6) was reduced by 2 to 3 orders of magnitude in total released. Zinc was decreased (Figure 2.7) by 1.5 to 2 orders of magnitude, while manganese (Figure 2.8) was decreased by 2 to 3 orders of magnitude by $Ca(OH)_2$ but only very little by $CaCO_3$.

Metal released from CARWA appeared less than from TEMPE cells given the same amendment. This difference may be due to the enhanced oxidation in the CARWA apparatus or due to the agitation (oxidation, mixing) of the sample chamber.

Table 2.3. Results of preliminary column investigations comparing CARWA to TEMPE with lime amendments.

SAMPLE NAME	VOLUME (ml)	PORE VOLUMES	pH	EC (mmhos/cm)	Copper SOLN. (mg/l)	Copper CUMULATIVE RELEASE (mg/kg-soil)	Zinc SOLN. (mg/l)	Zinc CUMULATIVE RELEASE (mg/kg/soil)
CARWA vs TEMPE - w/Lime Amendments								
CCC-1	22.91	.2668998	4.67	3.75	99.2	11.3584	653	74.7685
CCC-2	19.72	.4965035	5.38	4.43	75.8	18.8247	862	159.6755
CCC-3	18.63	.7132867	5.73	3.69	25.5	21.1962	592	214.7315
CCC-4	194	.9347319	5.95	3.31	9.9	22.1367	396	252.3515
CCC-5	795	1.855478	6.35	2.28	.5	22.3342	43.5	269.534
CCC-6	1606	3.720280	6.28	2.1	.5	22.7342	12.9	279.854
CCC-7	1607	5.585082	6.8	2.04	.5	23.1342	6.7	285.214
CCH-1	20.41	.2377622	5.2	1.86	2.8	.2856	16.9	1.7238
CCH-2	18.52	.4533800	5.88	2.23	2.1	.47985	7.9	2.45455
CCH-3	18.43	.6678322	6.73	2.19	.7	.54425	7.9	3.18135
CCH-4	194	.8892774	6.67	2.22	.5	.59175	4.5	3.60885
CCH-5	715	1.716783	6.65	2.05	.5	.76925	1.6	4.17685
CCH-6	1016	2.893939	7.9	1.94	.5	1.02175	.5	4.42935
CCH-7	947	3.989510	8.19	1.94	.5	1.25675	.5	4.66435
TCC-1	20.41	.2377622	5.47	2.56	44.6	4.5492	524	53.448
TCC-2	20.42	.4755245	5.72	4.17	7.8	5.3448	770	131.988
TCC-3	22.63	.7389277	5.99	3.76	2.1	5.5821	531	191.991
TCC-4	23.64	1.013986	5.9	3.18	.7	5.6647	395	238.601
TCC-5	555	1.655012	6.6	2.37	.7	5.8572	174	286.451
TCC-6	1236	3.088578	6.47	2.34	1.4	6.7182	108	352.871
TCC-7	1067	4.324009	6.35	2.31	.5	6.9832	83.6	397.179

Table 2.3 (continued).

SAMPLE NAME	VOLUME (ml)	PORE VOLUMES	pH	EC (mmhos/cm)	Copper SOLN. (mg/l)	Copper CUMULATIVE RELEASE (mg/kg-soil)	Zinc SOLN. (mg/l)	Zinc CUMULATIVE RELEASE (mg/kg/soil)
TCH-1	18.91	.2202797	5.48	1.13	36.1	3.41145	117	11.0565
TCH-2	19.22	.4440559	5.53	2.09	48.2	8.03865	36.1	14.5221
TCH-3	19.13	.6666667	5.67	2.13	20.5	9.9964	10.7	15.54395
TCH-4	20.54	.9055944	5.77	2.02	12	11.2264	5.6	16.11795
TCH-5	485	1.465035	6.09	1.97	3.5	12.0664	1.1	16.38195
TCH-6	1086	2.723776	6.64	1.93	.7	12.4444	1.1	16.97595
TCH-7	1007	3.889277	6.89	1.91	.5	12.6944	.5	17.22595

CCC - CARWA calcium carbonate

CCH - CARWA calcium hydroxide

TCC - TEMPE calcium carbonate

TCH - TEMPE calcium hydroxide

Table 2.3. (continued).

SAMPLE NAME	VOLUME (ml)	PORE VOLUMES	Manganese SOLN. (mg/l)	Manganese CUMULATIVE RELEASE (mg/ kg-soil)	Lead SOLN. (mg/l)	Lead CUMULATIVE RELEASE (mg/ kg/soil)
CARWA vs TEMPE - w/Lime Amendments						
CCC-1	22.91	.2668998	806	92.287	2.9	.33205
CCC-2	19.72	.4965035	1163	206.8425	2.8	.60785
CCC-3	18.63	.7132867	966	296.6805	2	.79385
CCC-4	194	.9347319	751	368.0255	1.1	.89835
CCC-5	795	1.855478	200	447.0255	.3	1.01685
CCC-6	1606	3.720280	133	553.4255	.03	1.04085
CCC-7	1607	5.585082	92.5	627.4255	.09	1.11285
CCH-1	20.41	.2377622	3.7	.3774	.4	.0408
CCH-2	18.52	.4533800	1	.4699	.4	.0778
CCH-3	18.43	.6678322	1	.5619	.2	.0962
CCH-4	194	.8892774	1	.6569	.1	.1057
CCH-5	715	1.716783	1	1.0119	.1	.1412
CCH-6	1016	2.893939	1	1.5169	.03	.15635
CCH-7	947	3.989510	1	1.9869	.03	.17045
TCC-1	20.41	.2377622	529	53.958	2.8	.2856
TCC-2	20.42	.4755245	1141	170.34	1	.3876
TCC-3	22.63	.7389277	900	272.04	.4	.4328
TCC-4	23.64	1.013986	700	354.64	.3	.4682
TCC-5	555	1.655012	369	456.115	.3	.5507
TCC-6	1236	3.088578	260	616.015	.3	.7352
TCC-7	1067	4.324009	201	722.545	.2	.8412

Table 2.3 (continued).

SAMPLE NAME	VOLUME (ml)	PORE VOLUMES	Manganese SOLN. (mg/l)	Manganese CUMULATIVE RELEASE (mg/kg-soil)	Lead SOLN. (mg/l)	Lead CUMULATIVE RELEASE (mg/kg/soil)
TCH-1	18.91	.2202797	134	12.663	2.6	.2457
TCH-2	19.22	.4440559	16	14.199	2.7	.5049
TCH-3	19.13	.6666667	1	14.2945	1.9	.68635
TCH-4	20.54	.9055944	1	14.397	1.5	.8401
TCH-5	485	1.465035	1	14.637	.8	1.0321
TCH-6	1086	2.723776	1	15.177	.4	1.2481
TCH-7	1007	3.889277	1	15.677	.2	1.3481

CCC - CARWA calcium carbonate

CCH - CARWA calcium hydroxide

TCC - TEMPE calcium carbonate

TCH - TEMPE calcium hydroxide

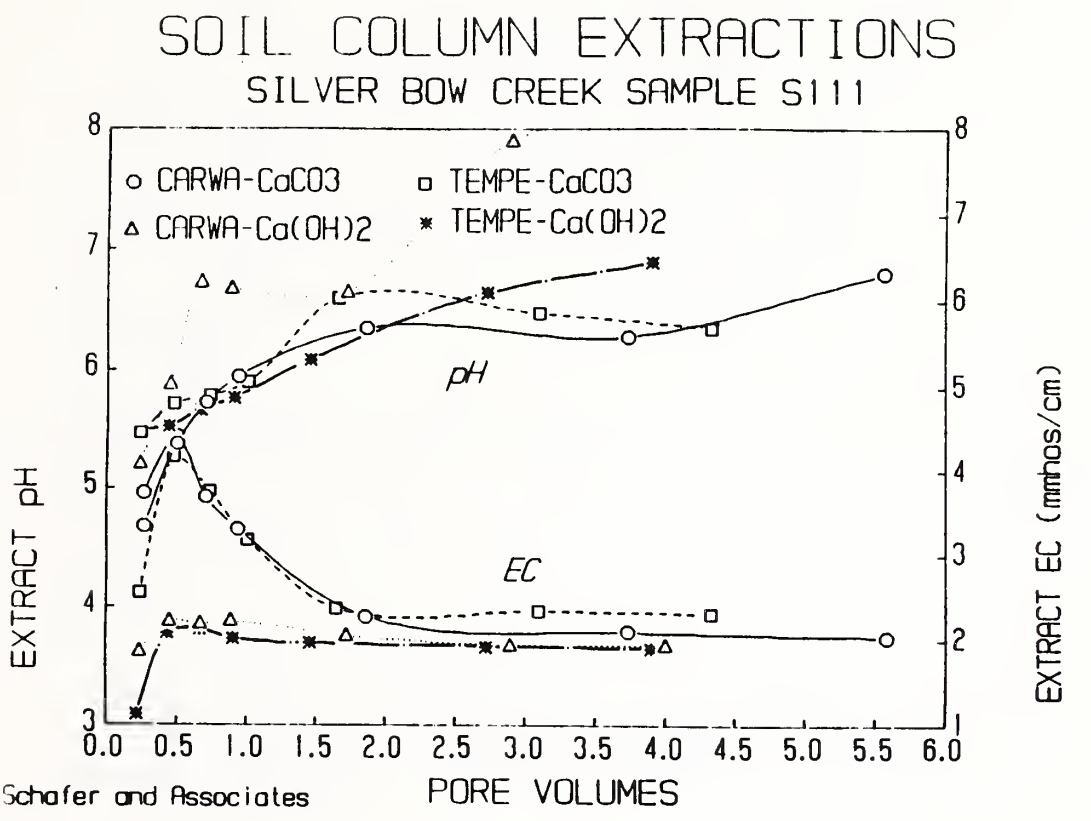

Figure 2.5. Extract pH and EC for lime-amended CARWA and TEMPE cells.

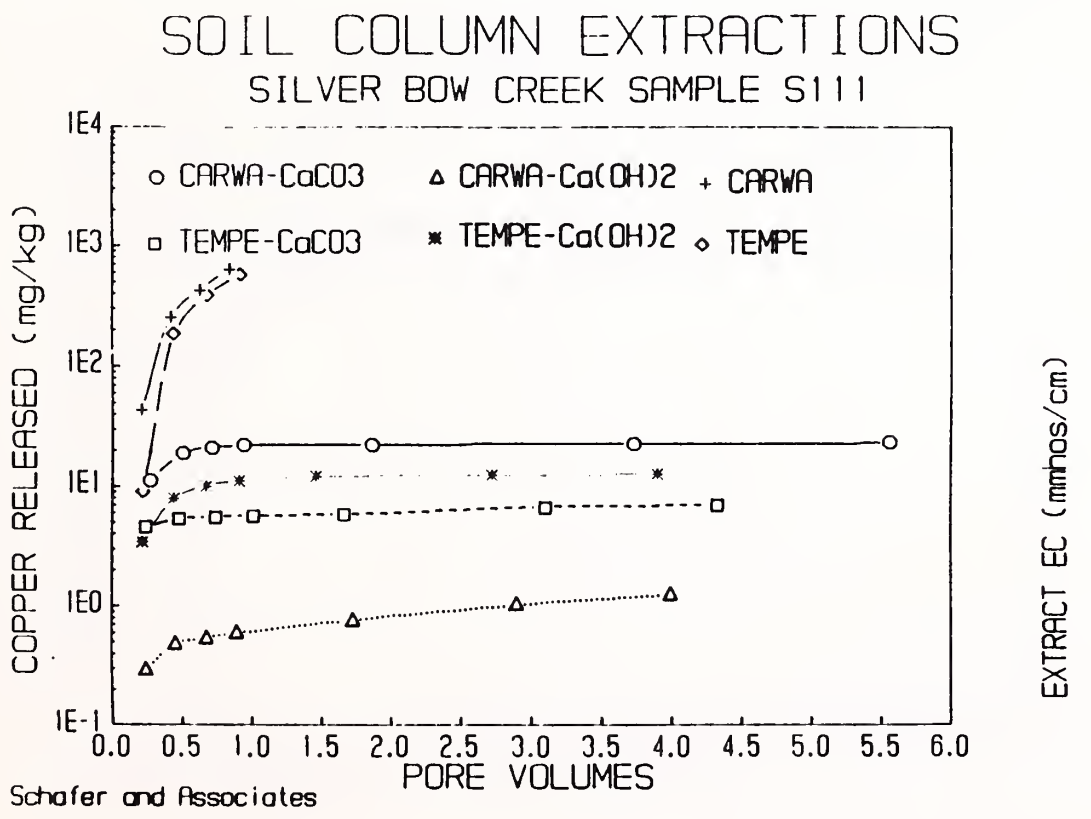

Figure 2.6. Cumulative copper released from lime-amended CARWA and TEMPE cells.

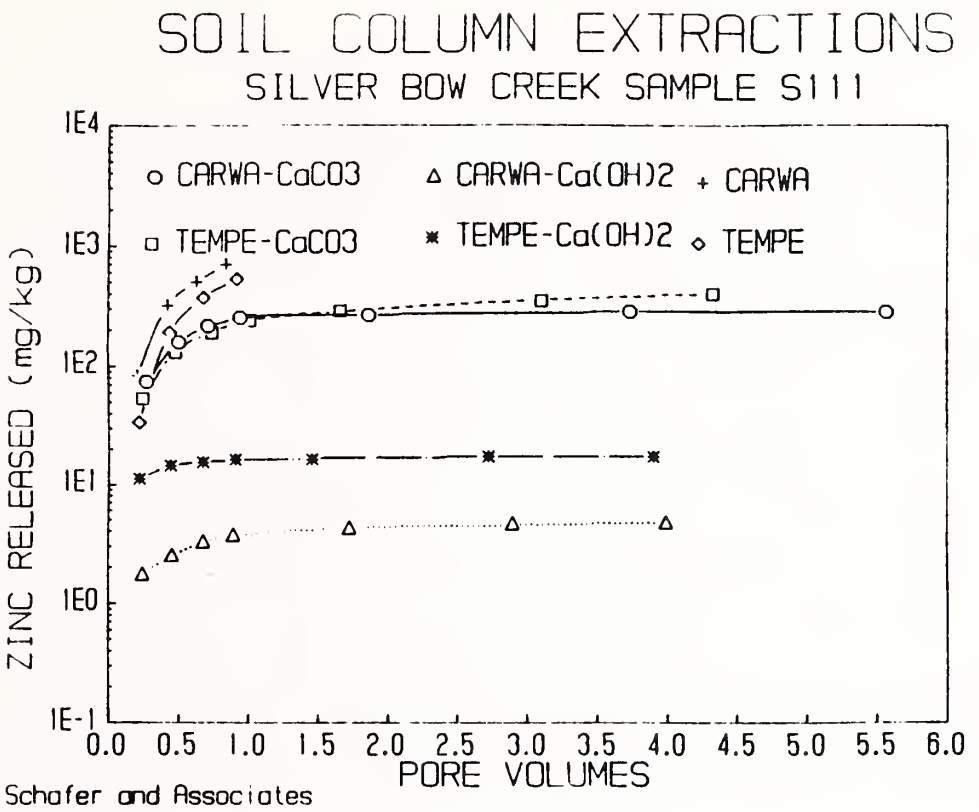

Figure 2.7. Cumulative zinc released from lime-amended CARWA and TEMPE cells.

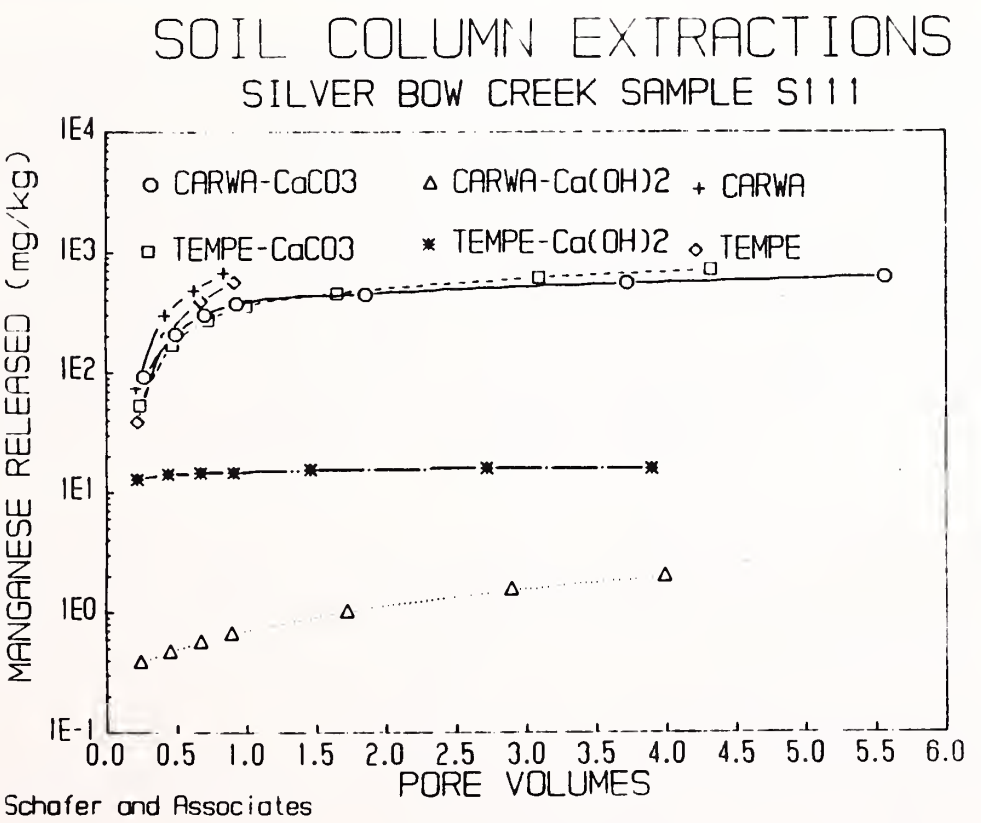

Figure 2.8. Cumulative manganese released from lime-amended CARWA and TEMPE cells.

Conclusion:

Neutralizing amendments dramatically reduced the concentration of metals in leachate. Differences between TEMPE cells and CARWA were less than differences between amendments. However, the reduced level of aeration and agitation in TEMPE cells may account for the slightly higher metal release of metals. The effects of aeration and stirring of TEMPE cells between cycles should be investigated. The importance of reaction rate is suggested by the differences between CaCO3 and Ca(OH)2. Equivalent amounts of each amendment were added (in terms of neutralizing capacity) but the faster reaction rate of Ca(OH)2 resulted in lower metal concentration in leachate. The effects of amendment equilibration time should be investigated. Formation of a precipitate in the TEMPE-CaCO3 samples indicates the need to filter and acidify samples collected. Filtration and acidification should be performed within 20 minutes of sample collection to prevent formation of precipitates.

2.2.2 Column Studies

Based on results of preliminary column investigations, the TEMPE cell has been chosen as the column type to be used in the STARS investigation. It is easier to run multiple columns with TEMPE, decontamination between column runs is easier, and control of the soil water content is easier. CARWA will be used to verify the results of the selected soil amendment treatments chosen on the basis of TEMPE cell runs. The CARWA data will thus be used for collaboration of TEMPE cell results. A Standard Operating Procedure (SOP-11, Appendix A) has been developed for operation of the CARWA system.

A Standard Operating Procedure (SOP-10, Appendix A) has been developed for operation of the TEMPE cells, leachate collection, and decontamination. Soil samples (200 grams) will be amended with single amendments or combinations and allowed to equilibrate for a specified period of time (to be determined based on results of Experiment 3). The amended sample will be brought to the saturation water content and loaded in the cleaned TEMPE cell. The cell will be extracted at 0.2 bars of pressure until the water delivery rate slows (10 minutes or more depending on chosen column height, Experiment

4). Leachate will be collected at roughly 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 2, and 2 to 4 pore volumes. Extracted volume will be converted to pore volume using bulk density and particle density data. Porosity of the sample will be calculated on the basis of field porosity which equals:

1-(bulk density/particle density)

Leachate will be measured for volume, pH, and EC in the laboratory. Leachates will be filtered through a 0.45 micron filter and preserved using 1 ml 1:1 HNO3 as a preservative. Leachates will be analysed by the contracted laboratory for the following parameters as described in the LAP:

Al, As, Ca, Cd, Cr, Cu, Fe, Mn, Mg, Pb, and Zn

Volume data will be transformed to pore volumes and metal data transformed to cumulative metal released on a soil weight basis and plotted as shown in Figures 2.3 through 2.8

After all leachates have been collected from a cell, a subsample of moist soil will be packaged and shipped to a laboratory for analysis of soluble and extractable metals and extractable As. The extractable levels will be compared to initial analyses for the sample. Analyses to be performed are listed below and are described in detail in the LAP.

Saturation extract
pH, EC, Al, As, Ca, Cd, Cr, Cu, Fe, Mn, Mg, Pb, Zn

NH4OAc pH 5.5 extract
Al, Cd, Ca, Cd, Cr, Cu, Fe, K, Mn, Mg, Na, Pb, Zn

Halvorson (12 N HCL extract) As

The QA/QC protocol for the leachate and soil samples is described in more detail in the LAP and QAPP. Standard forms for data quality control and sample tracking are included in Appendix B.

2.3 Task 9 : Review of Incorporation and Isolation Techniques

A review of literature and product information will be performed so that a summary of material incorporation techniques can be developed. Material soil incorporation techniques include the following broad categories:

Traditional agricultural tillage devices (6inch incorp.):

- harrow (light incorporation, poor mixing)
- cisel plow (intermediate incorporation, poor mixing)
- offset disk (intermediate incorporation and mixing)
- moldboard or one-way plow (good incorporation and mixing)

Deep Tillage Equipment:

- Vegreville plows (Vegreville, Alberta, 24 inch incorp.)
- Large moldboards (3 to 4 foot mixing, high draft required)

Highway Incorporation Equipment:

- Bo-Mag MPH series (roto-tiller machine to 20 inches)

Fluid Lime injector (mounted on D-9 Caterpiller ripper teeth)

Sequential incorporation on removed and replaced 6 inch lifts of material using traditional equipment.

Other methods or devices

These methods will be reviewed in terms of effectiveness, applicability to various waste types and settings (rocky materials, clayey materials, thixotropic sediments, poorly drained materials), depth of incorporation, and cost per unit volume or area of waste treated.

A review of literature will be performed so that a summary of waste isolation techniques can be developed. Applicable waste isolation techniques suitable for use in the vadose zone include the following:

- o cover-soil layers
- o capillary barriers

For example, use of thick (30 inches or deeper) cover-soil layers have been proposed for remediation (isolation) of problematic mine wastes. Thin soil layers (6 to 8 inches) have been shown to benefit establishment of plant cover over less toxic or over amended mine wastes where direct seeding has been unsuccessful. Capillary barriers could serve to :

- o protect applied cover-soil from being containated by underlying mine wastes.
- o protect chemically-amended mine waste from being contaminated by underlying mine wastes. This could occur when the mine waste depth exceeds the depth of amendment incorporation.
- o prevent surface salt accumulation on mine wastes at very harsh sites.

This effort will emphasize the evaluation of capillary barriers composed of coarse aggregates. Methods of preventing piping (downward infiltration of cover-soil into aggregates voids) will be investigated including use of layers of finer-graded aggregates above the barrier (Cedergren 1977), and use of synthetic permeable geotextiles (Trevira (polyester), Pro-Felt (polypropylene), National Seal Co.). A review of these isolation methods is necessary to determine their relevancy, reliability, cost, and constructability for consideration in the Feasibility Study.

2.4 Task 10 : LRPS Field Work

The Leachate Reduction Pilot Study (LRPS) was a precursor of the STARS investigation. The LRPS investigation is described in more detail in the 1986 RI data summary report by CH2M Hill (1987). Vegetation response and pH monitoring of the plots will be continued to learn as much as possible from this study. Observations of the plots indicate that liming and direct seeding with agronomic species into mine wastes was not effective. Addition of a 6 inch cover-soil layer consisting of tertiary sediment increased vegetation success.

Soil pH response in the LRPS plots was less than expected as reported in

the STARS work plan (Schafer and others 1987). Monitoring of pH in all plots will be performed to see if pH is still increasing on the plots 16 months after adding lime. Samples of the first replicate (block) of plots at each site will be collected (C to 6 inches) and analysed in the field for soil pH. Samples will be submitted for analysis of residual calcium carbonate to see if armoring of the lime by iron oxides have prevented equilibration of the lime. The SOP for measuring pH (SOP-1) will be followed. Methods to be used for analysis of CaCO3 are discussed in the LAP. If lime armoring is suggested by the presence of residual CaCO3 with pH levels below 6, then electron microscopy will be used to identify coatings. Details of the electron microscopy methods will be provided in a supplemental Technical Memo if the procedure is required.

The LRPS plots will have vegetation success documented by measuring canopy coverage of seeded and invader species. Plots will be treated for control of weeds using 2,4-D or Tordon if noxious weeds (leafy spurge, russian knapweed) are prevalent. Monitoring equipment currently installed in the plot area will be removed, cleaned, and stored for later use on the project.

3.0 QUALITY ASSURANCE

3.1 Overview

Data can vary in quality due to sampling methodology, sample preparation, analytical procedures, laboratory quality control, and available documentation. In order to develop a reliable data base which can be used for development of remedial alternatives for this enforcement-lead RI/FS, standards have been developed for data quality, and chain-of-custody controls. To meet this objective a project Quality Assurance Protection Plan (QAPP), (MSU and Schafer and Associates 1987) for the STARS project has been prepared. Field and laboratory methods proposed in this TSOP were developed in conformance with the QAPP (Table 3.1).

Table 3.1. QA/QC considerations for the Silver Bow Creek RI/FS Streambank Tailings Revegetation Study.

1. The Document Control Officer (DCO) will be properly trained in document control and personally responsible for all document custody.

2. The collection of specific descriptive or semi-quantitative data will always be performed by the same person(s), as specified in the appropriate Standard Operating Procedure (SOP).

3. Any deviations from SOP's which might be necessitated by field conditions must be approved by the DCO and noted in the logbook. Any changes will be communicated to the CH2M HILL site project manager (SPM) as soon as possible.

(continued)

Table 3.1 (continued).

4. Any serially numbered documents that are inadvertently destroyed must be recorded in the logbook. Voided forms will be archived and returned to CH2M Hill at the end of the project.

5. Any sampling equipment used to acquire more than one sample unit will be cleaned as described in the appropriate SOP to prevent cross contamination.

6. QA/QC samples will be inserted blind at a minimum frequency of 1 in 20 into the sample train.

7. On-site monitoring data collected in the field, column laboatory, or greenhouse will be subjected to rigorous data verification steps. Field data performed on laboratory samples will be encoded on customized forms with sample date, time, technician, Inorganic Traffic Report (ITR), and EPA tag number recorded.

8. All coolers will have a paperwork audit performd before being sent to the CLP (or equivalent).

3.2 Enforcement Aspects

The Silver Bow Creek RI/FS study area is a candidate CERCLA enforcement site. As such, all information and data collected during the investigation must be defensible in a court of law. The following criteria will be met to obtain defensible data:

* Strict chain-of-custody will be maintained for all samples, from the

time of collection to the completion of all analyses.

* All data will be of known quality. Field blanks, sample duplicates, cross-contamination blanks, and EPA control samples will be used to define the quality of data (refer to the STARS QAPP for full details).

3.3 QA/QC Objectives

The overall quality assurance objective for measurement data is to ensure that data of known and acceptable quality are provided. The data will be of the quality to withstand the scrutiny of litigation. In order to meet these objectives, the following QA/QC parameters will be addressed for data measurements:

Comparability
Completeness
Representativeness
Accuracy
Precision

Overall precision and accuracy targets for chemical contaminant measurements have been set at 90 percent confidence with a 10 percent deviation. Comprehensive implementation procedures for precision and accuracy assurance are referenced in the QAPP (MSU and Schafer and Associates 1987).

3.4 Quality Control

To measure the precision and accuracy of laboratory data for samples collected the following field quality control sample protocols have been established:

Table 3.2. Generalized QA/QC steps for mine waste and leachate samples.

---

1) Replicate samples will be inserted into the sample train at a frequency of one in twenty for leachate and mine waste samples. Additional replicates or other QA/QC samples will be used to provide a statistically defensible QA/QC data set for all sample runs.

2) Bottle blanks will be inserted into the sample train at a frequency of not less than one in twenty for leachate and mine waste samples.

3) Cross contamination blanks will be inserted into the sample train at a frequency of one in twenty, when neccessitated by sampling procedures, for leachate and water samples.

4) Blind standard samples will be inserted into the sample train at a frequency of one in twenty for leachate and mine waste samples.

The Standard Operating Procedure for insertion of QA/QC samples (SOP-6, Appendix A) addresses the methods and timing of QA/QC samples in greater detail.

Quantitative on-site measurements including soil and leachate pH, EC, and hydraulic conductivity, desorption curves, bulk density, and particle density will be subjected to QA/QC provisions to define the quality of field data. The following data verification steps will be implemented:

Table 3.3. Generalized QA/QC steps for field measurements.

---

1) Soil pH and SC (1:10) measurements will be performed in replicate on samples splits (1 in 20) to provide a measure of precision.

2) Instrument calibration with known standards and field checking EPA pH and SC standards at a frequency of 1 in 20 will be used to provide a measure of data accuracy.

3) Other on-site data collected will be replicated at a frequency of not less than 1 in 20 to provide a measure of precision. Accuracy estimates will be based on methodolgy cited and professional judgement due to the lack of available standards for these measurements.

4.0 SAMPLING AND MEASUREMENT

4.1 Overview of Sampling and Monitoring

A number of samples will be submitted for laboratory analysis as part of the TSOP. These will include waste samples, amendment samples, leachate samples, and leached soils. In addition, a number of measurements will be taken on-site during the TSOP. The approximate number of natural and QA/QC samples to be submitted are outlined in Table 4.1.

Table 4.1. Summary of samples to be submitted to a laboratory from the Streambank Tailings and Revegetation Study.

MATRIX	SOURCE	SAMPLE TYPES					
		NATURAL	STANDARDS	REPLICATES	BOTTLE BLANKS	CROSS-CONT. BLANKS	TOTAL
Soil	Initial waste sampling	35	2	2	2	4	45
Soil	Amendments	15	0	15	0	0	30
Water	Column leachates	630	32	32	32	32	758
Soil	Leached soils	126	7	7	0	0	140
Soil	LRPS samples	18	0	2	0	0	20

Measurements of soil and water pH and EC, leachate volume, bulk density, desorption characteristics, and field hydraulic conductivity will be conducted as described in section 2.0 and in the appropriate SOP's (Appendix A).

4.2 Equipment

The necessary field equipment, supplies and safety equipment required to carry out the Silver Bow Creek TSOP study are presented in Table 4.2.

Table 4.2. Monitoring, sampling and safety equipment list for the Silver Bow Creek STARS-TSOP.

CH2M HILL	MSU, SCHAFER AND ASSOCIATES
	(2) pH Meter and Electrode
200 ICHEM Jars - 8 ounce	pH 2, 4, 7 and 10 Buffer Standards
EPA Sample Tags - 1200	(2) Conductivity Meter and Probe
SAS Packing Lists - 40	Conductivity Standards
Custody Seals - 2 boxes	EPA standards pH and SC
Chain of Custody Records - 40	1000 ml Poly Beakers - 6
Federal Express Air Bills - 40	200 ml Poly Beakers - 6
	disposable styrofoam cups for
"Fragile" and "This Side Up"	pH and SC measurement
Labels	NBS River sediment standard (BFS)
ITR forms - 20	Squirt Bottles
	Kimwipes
	Meter Tape
	Bucket Auger
	Cakfield Probe
	Shovels

Table 4.2. (continued).

CH2M HILL	SCHAFER AND ASSOCIATES
	plastic sampling equipment
	Hand Trowel
	Plastic Ground Sheeting
	Custom Field Report Forms
	Clear Tape for Cooler Labels
	Container for Kimwipes in the Field - 2
	Masking Tape (to label jars) - 2 rolls
	Duct Tape (for inside coolers) - 5 rolls
	Distilled Water (for decontamination) - 40 gallons/field collection
	Thermometer (outdoor) - 1
	Munsell soil color book
	standard SCS soil morphology code book
	1 Inch Foam Rubber - 4 foot/ccoler
	Log Book (3 ring binder) - 1
	Log Book (bound)
	Site Map
	Portable Water Jug (2 gal.)
	Paper Drinking Cups
	Cotton Coveralls - 6
	10 rubber gloves
	100 plastic booties (disposable)
	100 garbage bags (disposal)

Table 4.2. (continued).

CH2M HILL	SCHAFER AND ASSOCIATES
	30 disposable dust masks
	Field health and safety manuals
	Cotton Gloves - 15 pair
	Hard Hats - 6
	Safety Glasses - 6 pair
	Boots (steel shank and toe) - 4 pair
	First Aid Kit
	Eye Wash Kit
	Fire Extinguisher
	Stretcher
	Clothes Brush
	Plastic Pails (for decontamination)
	Plastic Water Container
	Hand Soap
	Paper Towels
	Sharpies and Ball Point Pens
	35 mm Camera
	Color Print Film
	Plastic Ground Sheeting to set up Decontamination if necessary
	Funnel for Decontamination Water
	Wind Indicator Flag (surveying tape)
	Parafilm
	Handiwipes

4.3 Health and Safety

Health and safety plans have been developed for the Silver Bow Creek site by Schafer and Associates and MSU. Personnel to work on-site during sample collection will have received an EPA 40 hour health and safety training course for hazardous waste site workers which meets OSHA training standards. In addition, a medical monitoring plan will be in effect for all workers in accordance with OSHA requirements.

5.0 PROJECT PERSONNEL

Personnel and their assocaited responsibilities proposed for this project include the following:

Field and Laboratory Supervisors: D.J. Dollhopf and W.M. Schafer
Team Leader : M. Gitt, Troy Smith
Document Control Officer: M. Gitt, Robert Rennick
Safety Officer: M. Gitt (MSU), W. Schafer (Schafer & Assoc.)
Monitoring and Sampling: Troy Smith, M. Gitt, John Goering,
Robert Rennick, and additional technicians

Field and Lab Supervisors - reposible for all phases of study including collection and procurement of equipment and supplies, collection of mine waste samples, laboratory column implementation, data collection, sample preservation, custody , and shipping, and collection of notes and records.

Team Leader - responsible for routine implementation of column studies, data collection, and monitoring data under supervision of Lab Supervisor, directs technicians.

Document Control Officer - rsponsibilities are to 1) ensure that data and documents are released and distributed in accordance with EPA requirements, and 2) ensure custody of data and documents including prevention of unauthorized reproduction or alteration of records.

Safety Officers - responsible for assuring that provisions in the project Health and Safety Plans are followed. Includes project team briefings, and supervising adherance to plan.

Monitoring and Sampling - responsible for implementation, monitoring, and sampling under direction of supervisor and team leader.

6.0 LITERATURE CITED

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APPENDIX A

STREAMBANK TAILINGS AND REVEGETATION STUDY
STANDARD OPERATING PROCEDURES

SOP 1: SAMPLE pH
SOP 2: SAMPLE EC
SOP 3: SOIL HAND TEXTURE
SOP 4: SOIL SAMPLE COLLECTION
SOP 5: SOIL DESCRIPTION
SOP 6: QA/QC SAMPLES AND DOCUMENTATION
SOP 7: PRESERVING AND SHIPPING SAMPLES
SOP 8: BULK DENSITY AND DESORPTION DATA
SOP 9: FIELD SATURATED AND UNSATURATED HYDRAULIC CONDUCTIVITY
SOP 10: COLUMN EXTRACTION PROCEDURE
SOP 11: CARWA EXTRACTION METHOD

SOP 1
SAMPLE PH MEASUREMENT

Summary of Method

The pH of each sample will be determined electrochemically, using a glass combination electrode and a portable field pH meter with temperature compensation.

Sample Handling

Soil samples will be placed in styrofoam cups and a made into a saturation paste. Paste pH will be determined approximately 30 seconds after placing the pH electrode and thermistor in the soil paste. The measured value will be recorded on custom data forms (Appendix B). If leachate quantity is sufficient (>15 ml), a subsample will be placed in a plastic vial and pH measured directly. A form for recording data for leachates recovered from the TEMPE cells is included in Appendix B.

Interferences

The glass electrode is generally not subject to solution interferences fromcolor, turbidity, colloidal matter, oxidants, reductants or high salinity. Sodium error at pH levels greater than 10 can be reduced or eliminated by using a "low sodium error" electrode. Coatings of oily or particulate matter can impair electrode response, but can be removed by gentle wiping or detergent washing, followed by distilled water rinsing. An additional treatment with hydrochloric acid (1:9) may be used to remove any remaining film. Interferences with pH measurements caused by temperature will be compensated for by use of an automatic temperature-compensated field pH meter.

Apparatus

A portable Cole-Parmer (research grade) field pH meter with integral thermistor will be used. A combination glass electrode will be used.

Calibrations

The instrument/electrode system will be calibrated at two points that bracket the expected pH of the samples and are approximately three pH units or more apart. Buffers at pH 4, 7 and 10 will be available. The pH meter will also be adjusted for the temperature of the buffer solution. Calibration can be set in a EPROM chip in the field pH meter and will be checked daily for accuracy against pH buffer solutions. Results of calibration checks will be recorded on the same forms with measured pH of natural samples.

Standards

Primary EPA pH standards will be used for an additional QA/QC accuracy check at a frequency of one in 20 measurements. Standard samples will be prepared in accordance with EPA methodology.

Procedure

1. Standardize the meter and electrode system according to manufacturers recommendations.

2. Place the buffer solution into a clean glass beaker using sufficient volume to cover the sensing elements of the electrode.

3. Temperature of the solution will be recorded on the field sheets to provide a cross-check for anamolous data.

4. After rinsing and gently wiping the electrode, if necessary, it will be immersed into the sample beaker and gently agitated at a constant rate to homogenize the liquid sample or soil suspension. A slow stirring rate will minimize the air transfer at the air/water interface. Note and record pH and temperature.

The EPA standard method (150.1) for measurement of pH in water is attached.

Calculation

pH meters read directly in pH units. pH will be recorded to the nearest 0.1 unit.

Precision and Accuracy

Precision of water and soil pH measurements will be based on readings of sample splits. Accuracy will be based on calibration checks and values for blind field standards (EPA primary standards).

pH

Method 150.1 (Electrometric)

STORET NO.
Determined on site 00400
Laboratory 00403

1. Scope and Application
   1.1 This method is applicable to drinking, surface, and saline waters, domestic and industrial wastes and acid rain (atmospheric deposition).
2. Summary of Method
   2.1 The pH of a sample is determined electrometrically using either a glass electrode in combination with a reference potential or a combination electrode.
3. Sample Handling and Preservation
   3.1 Samples should be analyzed as soon as possible preferably in the field at the time of sampling.
   3.2 High-purity waters and waters not at equilibrium with the atmosphere are subject to changes when exposed to the atmosphere, therefore the sample containers should be filled completely and kept sealed prior to analysis.
4. Interferences
   4.1 The glass electrode, in general, is not subject to solution interferences from color, turbidity, colloidal matter, oxidants, reductants or high salinity.
   4.2 Sodium error at pH levels greater than 10 can be reduced or eliminated by using a "low sodium error" electrode.
   4.3 Coatings of oily material or particulate matter can impair electrode response. These coatings can usually be removed by gentle wiping or detergent washing, followed by distilled water rinsing. An additional treatment with hydrochloric acid (1 + 9) may be necessary to remove any remaining film.
   4.4 Temperature effects on the electrometric measurement of pH arise from two sources. The first is caused by the change in electrode output at various temperatures. This interference can be controlled with instruments having temperature compensation or by calibrating the electrode-instrument system at the temperature of the samples. The second source is the change of pH inherent in the sample at various temperatures. This error is sample dependent and cannot be controlled, it should therefore be noted by reporting both the pH and temperature at the time of analysis.
5. Apparatus
   5.1 pH Meter-laboratory or field model. A wide variety of instruments are commercially available with various specifications and optional equipment.

Approved for NPDES
Issued 1971
Editorial revision 1978 and 1982

5.2 Glass electrode.

5.3 Reference electrode–a calomel, silver-silver chloride or other reference electrode of constant potential may be used.

NOTE 1: Combination electrodes incorporating both measuring and reference functions are convenient to use and are available with solid, gel type filling materials that require minimal maintenance.

5.4 Magnetic stirrer and Teflon-coated stirring bar.

5.5 Thermometer or temperature sensor for automatic compensation.

6. Reagents

6.1 Primary standard buffer salts are available from the National Bureau of Standards and should be used in situations where extreme accuracy is necessary.

6.1.1 Preparation of reference solutions from these salts require some special precautions and handling[1] such as low conductivity dilution water, drying ovens, and carbon dioxide free purge gas. These solutions should be replaced at least once each month.

6.2 Secondary standard buffers may be prepared from NBS salts or purchased as a solution from commercial vendors. Use of these commercially available solutions, that have been validated by comparison to NBS standards, are recommended for routine use.

7. Calibration

7.1 Because of the wide variety of pH meters and accessories, detailed operating procedures cannot be incorporated into this method. Each analyst must be acquainted with the operation of each system and familiar with all instrument functions. Special attention to care of the electrodes is recommended.

7.2 Each instrument/electrode system must be calibrated at a minimum of two points that bracket the expected pH of the samples and are approximately three pH units or more apart.

7.2.1 Various instrument designs may involve use of a "balance" or "standardize" dial and/or a slope adjustment as outlined in the manufacturer's instructions. Repeat adjustments on successive portions of the two buffer solutions as outlined in procedure 8.2 until readings are within 0.05 pH units of the buffer solution value.

8. Procedure

8.1 Standardize the meter and electrode system as outlined in Section 7.

8.2 Place the sample or buffer solution in a clean glass beaker using a sufficient volume to cover the sensing elements of the electrodes and to give adequate clearance for the magnetic stirring bar.

8.2.1 If field measurements are being made the electrodes may be immersed directly in the sample stream to an adequate depth and moved in a manner to insure sufficient sample movement across the electrode sensing element as indicated by drift free (< 0.1 pH) readings.

8.3 If the sample temperature differs by more than 2°C from the buffer solution the measured pH values must be corrected. Instruments are equipped with automatic or manual

[1]National Bureau of Standards Special Publication 260.

compensators that electronically adjust for temperature differences. Refer to manufacturer's instructions.

8.4 After rinsing and gently wiping the electrodes, if necessary, immerse them into the sample beaker or sample stream and stir at a constant rate to provide homogeneity and suspension of solids. Rate of stirring should minimize the air transfer rate at the air water interface of the sample. Note and record sample pH and temperature. Repeat measurement on successive volumes of sample until values differ by less than 0.1 pH units. Two or three volume changes are usually sufficient.

8.5 For acid rain samples it is most important that the magnetic stirrer is not used. Instead, swirl the sample gently for a few seconds after the introduction of the electrode(s). Allow the electrode(s) to equilibrate. The air-water interface should not be disturbed while measurement is being made. If the sample is not in equilibrium with the atmosphere, pH values will change as the dissolved gases are either absorbed or desorbed. Record sample pH and temperature.

9. Calculation

9.1 pH meters read directly in pH units. Report pH to the nearest 0.1 unit and temperature to the nearest °C.

10. Precision and Accuracy

10.1 Forty-four analysts in twenty laboratories analyzed six synthetic water samples containing exact increments of hydrogen-hydroxyl ions, with the following results:

pH Units	Standard Deviation pH Units	Accuracy as Bias, %	Accuracy as Bias, pH Units
3.5	0.10	–0.29	–0.01
3.5	0.11	–0.00	
7.1	0.20	+1.01	+0.07
7.2	0.18	–0.03	–0.002
8.0	0.13	–0.12	–0.01
8.0	0.12	+0.16	+0.01

(FWPCA Method Study 1, Mineral and Physical Analyses)

10.2 In a single laboratory (EMSL), using surface water samples at an average pH of 7.7, the standard deviation was ±0.1.

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1. Standard Methods for the Examination of Water and Wastewater, 14th Edition, p 460, (1975).
2. Annual Book of ASTM Standards, Part 31, "Water", Standard D1293–65, p 178 (1976).
3. Peden, M. E. and Skowron, L. M., Ionic Stability of Precipitation Samples, Atmospheric Environment, Vol. 12, pp. 2343-2349, 1978.

SOP 2
SAMPLE EC MEASUREMENT

Summary of Method

Soil and leachate submitted for laboratory determination will have Electrical Conductance (EC) measured. The EC of a 1 to 10 soil to water suspension will be performed on soil samples where field measurements of EC are needed for sample location screening.

Electrical Conductivity will be measured using a self-contained portable conductivity meter (Cole-Parmer type). Temperature corrections will be made for solutions where the temperature is not 25^{o}. Electrical conductivity will be reported at 25^{o}.

Comments

The instrument will be standardized with KCL solution before daily use. Conductivity cell will be kept clean. Temperature variations and corrections generally represent the largest source of error.

Sample Handling and Preservation

Each soil sample will be prepared in styrofoam cups using a known volume measure scoop and a measured volume of water to yield a 1 to 10 soil solution ratio. The sample will be stirred and sediment allowed to settle. Specific conductance will be measured in the supernatant immediately following each pH measurement. The EC of leachate samples will be measured directly on a subsample if sample volume is sufficient (>12 ml).

Apparatus

Conductivity meter; range 1 to 10000 umhos per centimeter.

Conductivity cell; cell constant 1.0 or micro-dipping type cell with 1.0 constant. YSIH3Y03 or equivalent.

Thermometer.

Reagents

Standard potassium chloride solution, 0.01 M.

Cell Calibration

The analyst will calibrate the EC meter following manufacturers directions. Temperature compensation will be provided for solutions deviating

from 25 degrees (C). Calibration checks of the instrument with a KCl reference solution and with EPA standards will be recorded on data sheets with natural sample EC measurements.

Procedure

1. Follow manufacturer's directions for the operation of the instrument.

2. Determine temperature of sample within 0.5°C. Set the solution temperature on the EC meter to convert to 25°C:

3. Record measured values of EC in umhos/cm at 25°C, onto custom forms (Appendix B).

The EPA standard method (120.1) for meassurement of EC in water is attached.

Precision and Accuracy

Precision of water and soil EC measurements will be based on readings of sample splits. Accuracy will be based on calibration checks and values for blind field standards (EPA primary standards).

CONDUCTANCE

Method 120.1 (Specific Conductance, *u*mhos at 25°C)

STORET NO. 00095

1. Scope and Application
   1.1 This method is applicable to drinking, surface, and saline wates, domestic and industrial wastes and acid rain (atmospheric deposition).
2. Summary of Method
   2.1 The specific conductance of a sample is measured by use of a self-contained conductivity meter, Wheatstone bridge-type, or equivalent.
   2.2 Samples are preferable analyzed at 25°C. If not, temprature corrections aremade and results reported at 25°C.
3. Comments
   3.1 Instrument must be standardized with KCl solution before daily use.
   3.2 Conductivity cell must be kept clean.
   3.3 Field measurements with comparable instruments are reliable.
   3.4 Temperature variations and corrections represent the largest source of potential error.
4. Sample Handling and Preservation
   4.1 Analyses can be performed either in the field or laboratory.
   4.2 If analysis is not completed within 24 hours of sample collection, sample should be filtered through a 0.45 micron filter and stored at 4°C. Filter and apparatus must be washed with high quality distilled water and pre-rinsed with sample before use.
5. Apparatus
   5.1 Conductivity bridge, range 1 to 1000 μmho per centimeter.
   5.2 Conductivity cell, cell constant 1.0 or micro dipping type cell with 1.0 constant. YSI #3403 or equivalent.
   5.4 Thermometer
6. Reagents
   6.1 Standard potassium chloride solutions, 0.01 M: Dissolve 0.7456 gm of pre-dried (2 hour at 105°C) KCl in distilled water and dilute to 1 liter at 25°C.
7. Cell Calibration
   7.1 The analyst should use the standard potassium chloride solution (6.1) and the table below to check the accuracy of the cell constant and conductivity bridge.

Approved for NPDES
Issued 1971
Editorial revision, 1982

Conductivity 0.01 m KCl

°C	Micromhos/cm
21	1305
22	1332
23	1359
24	1386
25	1413
26	1441
27	1468
28	1496

8. Procedure
   - 8.1 Follow the direction of the manufacturer for the operation of the instrument.
   - 8.2 Allow samples to come to room temperature (23 to 27°C), if possible.
   - 8.3 Determine the temperature of samples within 0.5°C. If the temperature of the samples is not 25°C, make temperature correction in accordance with the instruction in Section 9 to convert reading to 25°.
9. Calculation
   - 9.1 These temperature corrections are based on the standard KCl solution.
     - 9.1.1 If the temperature of the sample is below 25°C, add 2% of the reading per degree.
     - 9.1.2 If the temperature is above 25°C, subtract 2% of the reading per degree.
   - 9.2 Report results as Specific Conductance, μmhos/cm at 25°.
10. Precision and Accuracy
    - 10.1 Forty-one analysts in 17 laboratories analyzed six synthetic water samples containing increments of inorganic salts, with the following results:

Increment as Specific Conductance	Precision as Standard Deviation	Accuracy as Bias, %	Accuracy as Bias, μmhos/cm
100	7.55	-2.02	-2.0
106	8.14	-0.76	-0.8
808	66.1	-3.63	-29.3
848	79.6	-4.54	-38.5
1640	106	-5.36	-87.9
1710	119	-5.08	-86.9

(FWPCA Method Study 1, Mineral and Physical Analyses.)

10.2 In a single laboratory (EMSL) using surface water samples with an average conductivity of 536 μmhos/cm at 25°C, the standard deviation was ±6.

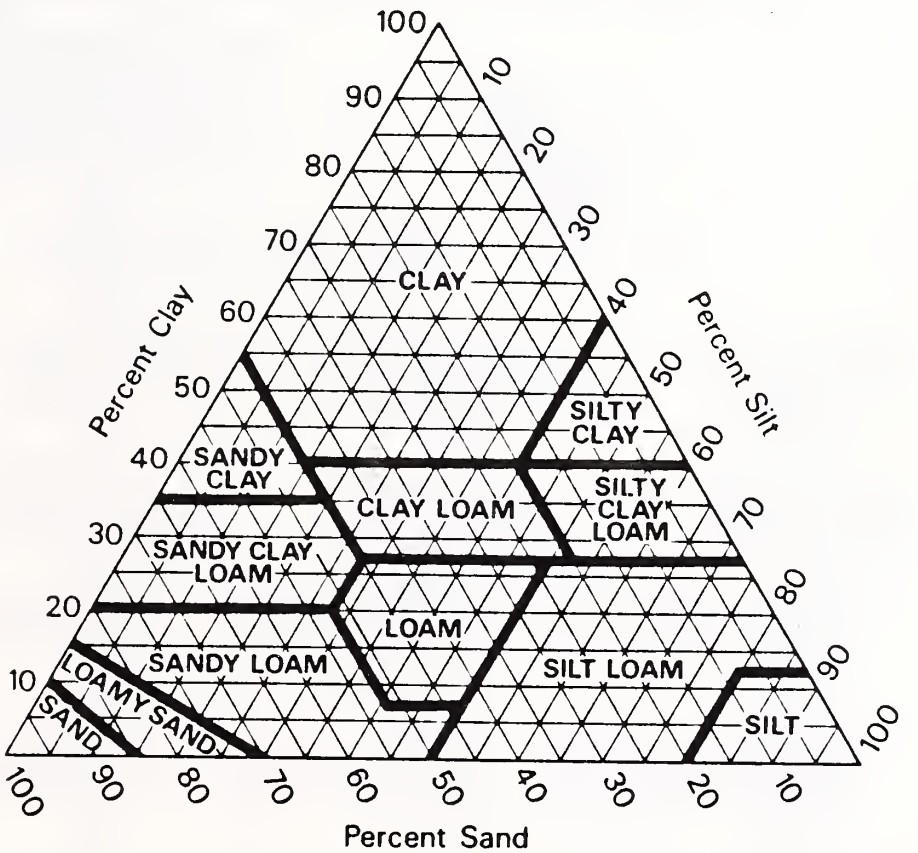
Bibliography

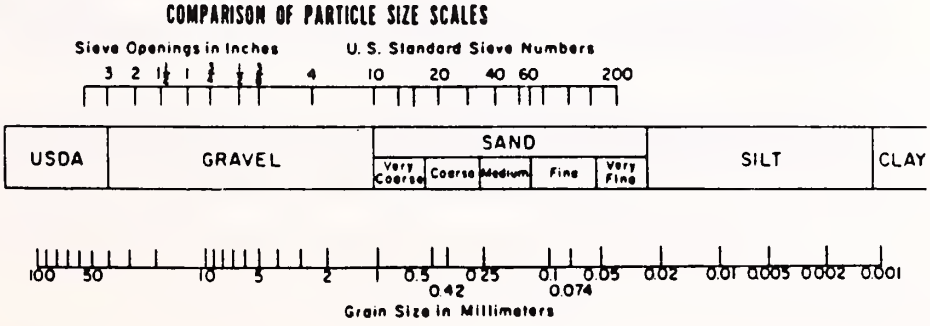
1. The procedure to be used for this determination is found in:
   Annual Book of ASTM Standards Part 31, "Water," Standard D1125-64, p. 120 (1976).
2. Standard Methods for the Examination of Water and Wastewater, 14th Edition, p. 71, Method 205 (1975).
3. Instruction Manual for YSI Model 31 Conductivity Bridge.
4. Peden, M. E., and Skowron. "Ionic Stability of Precipitation Samples," Atmospheric Environment, Vol. 12, p. 2343-2344, 1978.

SOP 3
FIELD SOIL TEXTURE (HAND TEXTURE)

Soil texture is thought to be an important parameter influencing the chemistry, hydraulic properties, and remedial design for streambank waste deposits. Estimation of soil texture class is a component of soil horizon descriptions. Therefore, estimates of soil texture will need to be made in the field.

Soil texture class is determined by measuring or estimating the amount of sand (.05 to 2 mm size fraction), silt (.002 to .05 mm size fraction), and clay (less than .002 mm size fraction) in a soil sample. The relative amounts of each particle size are used to place the soil on a trilinear diagram (below) which is broken into texture classes.

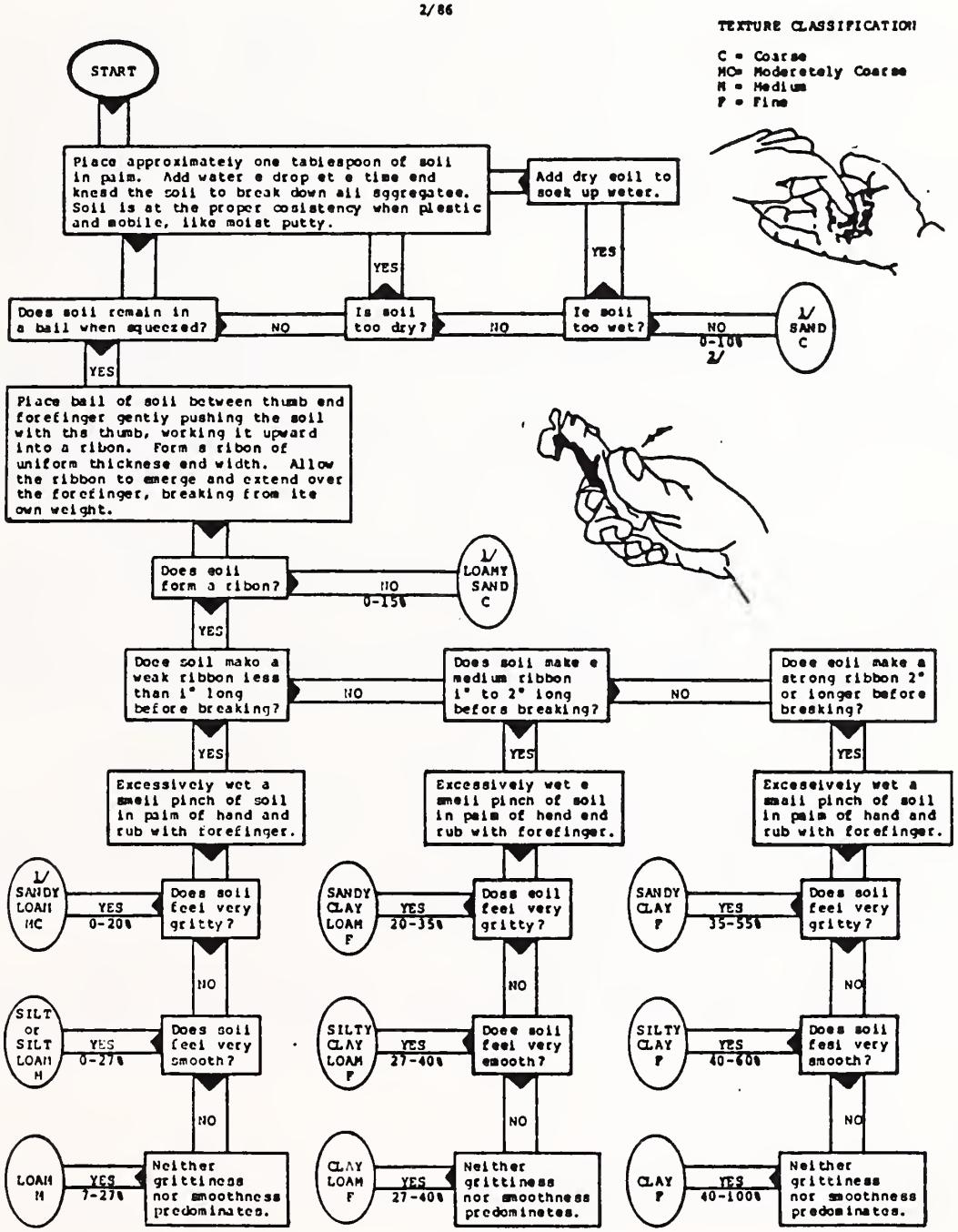




The method for determining soil texture by estimation is known as "hand texturing" or the "feel method". A description of this method is shown below. All hand textures should be performed by personnel experienced in this method. Precision and accuracy will be provided by professional judgement.

DETERMINING SOIL TEXTURE BY THE "FEEL METHOD" 1/

2/86


TEXTURE CLASSIFICATION
C = Coarse
MC= Moderately Coarse
M = Medium
F = Fine
START
Place approximately one tablespoon of soil in palm. Add water a drop at a time and knead the soil to break down all aggregates. Soil is at the proper consistency when plastic and mobile, like moist putty.
Add dry soil to soak up water.
YES
Does soil remain in a ball when squeezed?
NO
Is soil too dry?
NO
Is soil too wet?
NO
1/ SAND C
0-10%
2/
YES
Place ball of soil between thumb and forefinger gently pushing the soil with the thumb, working it upward into a ribon. Form a ribon of uniform thickness and width. Allow the ribbon to emerge and extend over the forefinger, breaking from its own weight.
Does soil form a ribon?
NO
0-15%
1/ LOAMY SAND C
YES
Does soil make a weak ribbon less than 1" long before breaking?
NO
Does soil make a medium ribbon 1" to 2" long before breaking?
NO
Does soil make a strong ribbon 2" or longer before breaking?
YES
Excessively wet a small pinch of soil in palm of hand and rub with forefinger.
1/ SANDY LOAM MC
YES
0-20%
Does soil feel very gritty?
SANDY CLAY LOAM F
YES
20-35%
Does soil feel very gritty?
SANDY CLAY F
YES
35-55%
Does soil feel very gritty?
NO
SILT or SILT LOAM M
YES
0-27%
Does soil feel very smooth?
SILTY CLAY LOAM F
YES
27-40%
Does soil feel very smooth?
SILTY CLAY F
YES
40-60%
Does soil feel very smooth?
NO
LOAM M
YES
7-27%
Neither grittiness nor smoothness predominates.
CLAY LOAM F
YES
27-40%
Neither grittiness nor smoothness predominates.
CLAY F
YES
40-100%
Neither grittiness nor smoothness predominates.

1/ Sand particle size should be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of very fine sand are not visible without magnification and there is a gritty feeling to a very small sample ground between teeth. Some fine sand particles may be just visible. Medium sand particles are easily visible. Examples of sand size descriptions where one size is predominant, are: very fine sand, fine sandy loam, loamy coarse sand.

2/ Clay percentage range.

3/ Modified from: Thien, Steve J.; Kansas State University, 1979 Jour. Agronomy Education.

SOP 4
SOIL SAMPLE COLLECTION

Bulk soil samples will be collected from the face of hand-dug soil excavations. Samples will be collected from the 0 to 15 inches depth increment unless contrasting materials are encountered in the upper 15 inches. Candidate sample layers located below the surface (i.e. buried soils) will also be collected from a 15 inch depth increment unless contrasting materials are found. Each sample collected will be deposited directly into a plastic tub by shoveling with a cleaned steel shovel. The sample will then be mixed and any clods will be broken up.

Approximately 300 pounds of sample will be collected from each sample location and placed into 2 large plastic garbage cans. The bulk sample will be oven-dried in the laboratory by spreading and periodically rolling on a plastic sheet in large drying ovens secured with custody seals during use. Samples will be homogenized in a mechanical mixer. The mixed, air-dry sample will be replaced into large plastic garbage cans for storage.

A representative subsample of the bulk sample will be obtained for submission to the laboratory by coring the middle of each sample container fromtop to bottom with a 3-inch diameter steel bucket auger. The material obtained by augering will be rolled and quartered on a canvas sheet with a spilt placed in 32 oz. IChem jar for submission to the laboratory. Additional details on packaging, and documentation on soil samples is provided in SOP-7.

Between sample collection, all equipment will be cleaned thoroughly with a stiff brush and rinsed with distilled water and paper towels. A rinsate blank will be used as a cross-contamination blank at a frequency of one in each 20 bulk samples. The kimwipe blank will be prepared by wiping the sampling device and placing the kimwipe in a sample container.

Samples collected from the laboratory column apparatus will be placed moist into IChem jars and immediately cooled to 4 degrees (C) and shipped to a laboratory for analysis.

SOP 5
SOIL MORPHOLOGY AND SITE DESCRIPTION METHOD

A description of each soil sample location will be developed. The description will consist of a generalized description of the site as well as a description of the morphological features of each soil horizon.

The site desciption will include an assessment of a number of generalized features including sample location, soil classification, site number, number of horizons described, soil parent material, land cover type, dominant and co-dominant species, approximate canopy cover and percent bare ground, land use, soil drainage class and permeability, evidence of erosion, slope, aspect, landscape position, landform, proximity to the Silver Bow Creek channel, depth of mine waste and depth to ground water (if present). Features described will be encoded on field forms developed for this purpose. The forms are used to input data into the PEDFORM system, a proprietary database system developed for use with Dbase III+ so that soil morphology data can be readily linked to laboratory chemical and physical data. Numerical codes used in PEDFORM are attached.

Soil morphological features will be described for individual horizons described in each soil excavation. Horizon depths will conform to sampling depths for ease in interpretation. Horizons will be diferentiated using professional judgement based on discernable differences in soil characteristics such as parent material, texture, color, structure, consistence, or other features. For each horizon, the following features will be described: depth, texture, moist and dry color (hue, value, and chroma using Munsell color notation), texture (SOP-3), sructure, consistence, roots, pores, effervescence in HCl, and boundary distinctness, and shape. Horizon descriptions and horizon names will be developed in accordance with procedures established by the National Cooperative Soil Survey (SCS staf, 1975).

Table A-1. Index for parent material, vegetation, and land use codes in the PEDFORM system.

Code	Parent Material	Code	Vegetation	Code	Land Use
01	volcanic ash	01	mixed coniferous	01	commercial forest
02	loess	02	ponderosa pine	02	non-comm. forest
03	glacial outwash	03	lodgepole pine	03	forest
04	glacial till	04	spruce-fir	04	range
05	lacustrine	05	larch-fir	05	dryland crop
06	peat	06	Douglas-fir	06	irrigated crop
07	muck	07	mixed deciduous	07	irrigated hay
08	residual sandst.	08	cottonwood	08	dryland hay
09	residual shale	09	aspen	09	pasture
10	residual siltst.	10	trees	10	residential
11	residual limest.	11	dryland crop	11	urban
12	resid. crystalline	12	irrig. field crop	12	disturbed land
13	mixed alluvium	13	row crops	13	strip mine
14	alluvial	14	horticultural crop	14	mill tailings
15	colluvial	15	riparian	15	mine dump
16	soliflucate	16	mixed shortgrass	16	wildland
17	sandst. alluvium	17	mixed midgrass	17	landfill
18	shale alluvium	18	shrubs & grasses		
19	siltst. alluvium	19	halophytic		
20	crystalline alluv.	20	sedges & rushes		
21	limestone alluv.	21	perennial forage		
22	tailings	22	tame pasture		

Table A-2. Index for codes for drainage, permeability, erosion, landscape, position, and landform type in the PEDFORM system.

Code	Drainage	Code	Permeabililty	Code	Erosion
01	very poor	01	very slow	01	none
02	poor	02	slow	02	slight
03	poor to moderate	03	slow to medium	03	moderate
04	moderate	04	medium	04	severe
05	well	05	medium to rapid	05	slight-wind
06	well to excessive	06	rapid	06	moderate-wind
07	excessive	07	very rapid	07	severe-wind
08	altered, drained				
09	altered, wetted				

Table A-3. Index for landscape position and landform codes in the PEDFORM SYSTEM.

Code	Landscape Position	Code	Landform
01	crest	01	sedimentary upland
02	ridge	02	mountains
03	upper midslope	03	playa
04	midslope	04	alluvial fan
05	lower midslope	05	sand dune
06	footslope	06	glacial outwash
07	level slope	07	ground morraine
		08	alpine till
		09	terrace
		10	floodplain
		11	plateau
		12	solifluction lobe
		13	patterned ground
		14	backswamp
		15	landslide
		16	badlands
		17	disturbed land
		18	talus

Table A-4. Index for texture codes in the PEDFORM system.

Code	Symbol	Texture	Code	Symbol	Texture
--- USDA TEXTURE ---			--- FAMILY TEXTURE ---		
01	s	sand	20	sndy	sandy
02	ls	loamy sand	21	colo	coarse loamy
03	lfs	loamy fine sand	22	cosi	coarse silty
04	lvfs	loamy very fine s.	23	filo	fine loamy
05	sl	sandy loam	24	fisi	fine silty
06	fsl	fine sandy loam	25	fine	fine
07	vfsl	v. fine sandy loam	26	vf	very fine
08	l	loam	27	sskl	sandy skeletal
09	sil	silt loam	28	lskl	loamy skeletal
10	scl	sandy clay loam	29	cskl	clayey skeletal
11	cl	clay loam	30	frag	fragmental
12	sicl	silty clay loam	31	ashy	ashy
13	sc	sandy clay	32	mdl	medial
14	c	clay	33	hstc	histic
15	sic	silty clay	34	fbrc	fibric
16	cos	coarse sand			
17	fs	fine sand			
18	vfs	very fine sand			
19	si	silt			

Table A-5 . Index for structure grade, size, and kind used in the PEDFORM system.

Code	Structure grade	Code	Structure kind
01	massive	01	massive
02	weak:peds barely obsevable in place and when disturbed peds remain	02	platy
03	weak to moderate	03	granular
04	moderate: peds easily observable and when disturbed most of material consists of peds.	04	subangular blocky
05	moderate to strong	05	angular blocky
06	strong: peds distinnctly visible, when disturbed entire soil mass is aggregated	06	prismatic
		07	columnar
		08	wedge

Code	Size Class	Diameter of granules	Thickness of plates	Diameter of blocks	Diameter of prisms
		(mm)			
01	very fine	<1	<1	<5	<10
02	fine	1-2	1-2	5-10	10-20
03	medium	2-5	2-5	10-20	20-50
04	coarse	5-10	5-10	20-50	50-100
05	very coarse	>10	>10	>50	>100

Table A-6 . Index for soil consistence in the PEDFORM system.

Code	Dry consistence	Code	Moist consistence
01	loose	01	loose
02	soft: easily crushes to powder	02	very friable: crushes under gentle pressure
03	slightly hard: easily broken between thumb and finger	03	friable: crushes easily under moderate pressure between"THUMB and finger
04	hard:easily broken in hand	04	firm: crushes under moderate pressure between thumb and finger
05	very hard: broken in hands with difficulty	05	very firm: barely crushable between thumb and finger
06	extremely hard: cannot be broken in hands	06	extremely firm: crushes under strong pressure in hand
07	indurated	07	indurated

Code	Wet stickiness	Code	Wet plasticity
01	nonsticky: no adherence	01	nonplastic: no wire formed
02	slightly sticky: adheres to thumb and finger but comes off one cleanly	02	slightly plastic: wire forms but easily deformed
03	sticky: soil adheres and stretches before pulling apart	03	plastic: wire forms, moderate pressure required to deform
04	very sticky: soil adheres to both fingers	04	very plastic: wire forms, much pressure required to deform

Table A-7. Index for root abundance, size, and location in the PEDFORM system.

Code	Size
01	none
02	very fine (0.1-1mm)
03	fine and very fine
04	fine (1-2mm)
05	medium and fine
06	medium (2-5mm)
07	coarse and medium
08	coarse (>5mm)
09	fine and coarse

Code	Location
01	none
02	throughout horizon
03	between peds
04	flattened in cracks
05	flattened around rocks
06	mat at top of horizon

Code	Abundance CLASS	Very fine (NUMBER/DM**2)	Fine (NUMBER/DM**2)	Medium (NUMBER/DM**2)	Coarse (NUMBER/DM**2)
01	none				
02	trace				
03	few	<10	<10	<1	<1"
04	few to common				
05	common	10-100	10-100	1-10	1-5"
06	common to many				
07	many	>100	>100	>10	>5"

Table A-8. Index for pore abundance, size, and kind in the PEDFORM system.

Code	Size	Code	Kind
01	none	01	none
02	micro and very fine	02	irregular and tubular
03	very fine (.1-.5mm)	03	tubular
04	fine and very fine	04	tubular continuous
05	fine (.5-2mm)	05	tubular discontinuous
06	medium and fine	06	vesicular
07	medium (2-5mm)	07	vesicular and tubular
08	coarse and medium	08	interstitial voids between peds
09	coarse (>5mm)	09	interstitial voids between rocks

CODE	ABUNDANCE CLASS	VERY FINE	FINE	MEDIUM	COARSE
		----- (NUMBER/DM**2) -------			
01	none				
02	trace				
03	few	<10	<10	<1	<1"
04	few to common				
05	common	10-100	10-100	1-10	1-5"
06	common to many				
07	many	>100	>100	>10	>5

Table A-9. Index for effervescence in HCl, and horizon boundary in the PEDFORM system.

Code	Effervescence	Lower Horizon Code	Distinctness	Boundary Code	Shape
01	noncalcareous	01	abrupt <1in.)	01	smooth
02	slight	02	clear (1-2.5in.)	02	wavy
03	moderate	03	gradual (2.5-5in.)	03	irregular
04	violent	04	diffuse (>5in.)	04	broken
		05	arbitrary	05	arbitrary
		06	not reached	06	not reached

SOP 6
QA/QC SAMPLES AND DOCUMENTATION

This SOP addresses the types of QA/QC samples and their method and timing of insertion into the sample matrix. These procedures are the responsibility of the DCO. QA/QC samples will not have any unique identifying codes that could enable the contract laboratory or others to identify these samples as such and thereby bias them in any way. There may be, however, obvious physical differences between blind field standards and natural samples taken at the site. The QA/QC samples will be completely identified only on the Sample Identification Matrix, which will not be sent to the contract laboratory. Samples will be identified as:

N	Natural sample
R	Replicate sample
BFS	Blind field standard (NBS)
BB	Bottle blank
CCB	Cross-contamination blank

In general, a QA/QC sample will be inserted into the sample matrix at a frequency of 1 roughly 1 in 20, or 5%. Natural soil samples will be collected with plastic sampling implements and placed in 8 ounce ICHEM jars. Natural water (leachate) samples will be placed in IChem bottles after filtration and preservation with 1:1 HNO3.

Replicate samples will consist of a natural soil samples placed on canvas sheet and mixed thoroughly. The sample will be split by quartering the canvas cloth. Replicate water samples will be split and individually filtered and preserved. All pH and EC measurements should be performed on both sample splits.

The cross-contamination blank will consist of a kim-wipe used as a wipe test of the sampling device after decontamination. Sample equipment decontamination will consist of brushing followed by a distilled water rinse. The cross-contamination blank for the column study (SOP-10) will consist of distilled water leached through the TEMPE cell after the appropriate decontamination procedure.

The "bottle blank" soil sample will consist of a clean kim-wipe placed in an I-CHEM jar. The bottle blank for water will consist of distilled-deionized water filtered and preserved and placed in a IChem bottle.

NBS blind field standards will be poured directly into an I-CHEM jar and submited as the blind field standard. Approximately 5 grams of NBS standard will be used. EPA and NBS standards for water samples will be prepared in accordance with the suppliers directions.

Documentation

Complete and accurate sample documentation is essential to insure data integrity and validity. It will be the responsibility of the Document Control Officer (DCO) to assure that all QA/QC goals are met. A final check to see that all proper physical sample handling, QA/QC, and and data control protocols have been followed will help insure a useable data base.

The documents to be completed during the project may include:

1. Site / Horizon description form
2. pH and EC data form
3. column run / leachate form
4. ITR form
5. Chain-of-Custody Records
6. SAS Packing Lists
7. EPA sample tags
8. Rapid Carrier Forms
9. Daily Site Condition/Activity Form

Examples of each of the forms can be found in Appendix B. All documents will follow strict chain-of-custody procedures. While documents are being prepared in the field or laboratory, custody will be mantained by the DCO. After the work has been completed, photocopies of the documents will be used as working documents. A logbook of field and laboratory work will be maintained with daily natations of work performed, accomplishments, samples collected, deviations from SOP's and justification (if any).

The purpose of documents is to contain enough information to reconstruct the sampling event without the aid of the technical crew. It will be the DCO's responsibility to assure the sufficient detail, correctness and legal integrity of the documents. All entries will be made in indelible ink and all corrections will consist of initialed and dated line-out deletions. At the completion of each sampling day, the entries will be initialed and dated by both the DCO and the original author. A line will be drawn through the remaining page to prevent unauthorized additions.

SOP 7
SAMPLE PREPARATION AND PRESERVATION

The DCO will direct all packaging and shipping procedures. Each scientist and technician involved in obtaining samples will be responsible for a specific task to ensure consistency.

Procedure

1. All soil sampling, decontamination, QA/QC samples, sample splits, and pH and SC measurement should be completed for each sample.

2. Upon filling a soil or water sample container, a completed EPA custody seal over the top of the container. The custody seal serves two purposes. It secures custody of the sample and it secures the lid of the container.

3. An EPA sample tag is completed by a field scientist, and is taped securely to the sample container.

4. The samples will then be placed into a cooler labeled "SOIL SAMPLES" or "WATER SAMPLE", with the site identification and date also written on the cooler top. Since soil samples will be in glass ICHEM jars, they will be packed with vermiculite to prevent breakage. The cooler will be packed full, so there is no empty space for the contents to move about.

5. When the cooler is full, or when the sample collection is complete, a Chain-of-Custody form, Inorganic Traffic Report (ITR) (for Routine Analytical Services - RAS), or Special Analytical Service (SAS) packing list, and sample identification matrix form will be completed. A prenumbered airbill will be assigned to that cooler. Examples of all forms are in Appendix B.

6. The DCO will double check the forms to assure those samples mentioned on the COC, ITR and SAS are all present and accounted for in the cooler. He/she will document this on the ITR, SAS Packing List and Sample ID Matrix.

7. The cooler will be clearly marked "FRAGILE/THIS SIDE UP" on all four sides and the top as appropriate.

8. The DCO will then place the proper COC, ITR and SAS Packing Lists in a Ziploc bag, taped to the inside roof of the cooler.

9. The DCO or scientist will then close the cooler and affix the airbill to the top of the cooler.

10. The DCO or field scientist will then seal the cooler and place the

appropriate COC seals (one in front and one in back), signed and dated, on the cooler.

11. The field scientist will then place fiberglass tape over the custody seals and around the cooler, making sure everything is secure.

12. The cooler will be labeled as to type of samples and date of sampling, with a large felt-type pen.

13. The cooler(s) will then be transported to a secure storage facility, where they can be kept under custody until they are shipped.

SOP 8
BULK DENSITY AND DESORPTION DATA

Three samples will be collected adjacent to each bulk soil sample location using a specialized soil core sampler adapted to use with the TEMPE cells. An undisturbed core will be collected in a brass cylinder of known volume so that bulk density can be determined based on sample dry weight. The method for measurement of bulk density by the core method (ASA 1965) is attached. Particle density of a sample split from the bulk density samples will be determined. A method for determination of particle density is attached (ASA 1965).

In addition, the samples used for bulk density determination will be saturated and placed in the TEMPE cells. The cell weight will be determined at 0, -0.1, -0.2, -0.5, and -1.0 bars of water potential. These data will be plotted to obtain a desorption curve. Fifteen bar water content will be determined on a disturbed sample. The TEMPE cells will not maintain pressure beyond 1 bar. The standard method following (ASA 1965) will be modified to use TEMPE cells rather than pressure membrane equipment.

Precision of these measurements will be provided by obtaining three values at each sample location. Accuracy will be provided by professional judgement.

METHODS OF SOIL ANALYSIS

Part 1

Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling

C. A. BLACK, *Editor-in-Chief*
and
D. D. EVANS
J. L. WHITE
L. E. ENSMINGER
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R. C. DINAUER, *Managing Editor*

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30 Bulk Density[1]

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30–1 GENERAL INTRODUCTION

Soil bulk density D_b is the ratio of the mass to the bulk or macroscopic volume of soil particles plus pore spaces in a sample. The mass is determined after drying to constant weight at 105°C., and the volume is that of the sample as taken in the field.

Bulk density is a widely used value. It is needed for converting water percentage by weight to content by volume, for calculating porosity when the particle density is known, and for estimating the weight of a volume of soil too large to weigh conveniently, such as the weight of a furrow slice, or an acre-foot.

Bulk density is not an invariant quantity for a given soil. It varies with structural condition of the soil, particularly that related to packing. For this reason it is often used as a measure of soil structure.

The clod method, core method, and excavation method consist essentially of drying and weighing a known volume of soil. These methods differ principally in the way the sample of soil is obtained. A different principle is employed with the radiation method. Transmitted or scattered gamma radiation is measured; and, with suitable calibration, the density of the combined liquid-solid components of a soil mass is determined. Correction is then necessary to remove the component of density attributable to liquid that is present. The radiation method is an *in situ* method.

Clod and core methods have been used for many years. Excavation methods were developed in recent years, chiefly by soil engineers. Radiation methods are relatively new, having been developed since 1950.

In most agricultural soils work, bulk density is expressed in grams per cubic centimeter (g. cm.$^{-3}$). In these units volume weight is equal, and bulk specific gravity (or apparent specific gravity) is nearly equal, numerically, to bulk density. The term bulk density is preferred over the terms

[1] Paper No. 4433 of the Scientific Journal Series, Minnesota Agr. Exp. Sta., St. Paul.

volume weight, bulk specific gravity or apparent specific gravity. Because of its definition, in terms of mass rather than weight, it has universal applicability, and conforms more closely to accepted physical terminology than does volume weight. Specific gravity terms are relative terms, being the ratio of the mass of a dry bulk volume of soil to the mass of an equal volume of water. Since the mass of water per unit volume varies with temperature, bulk specific gravity varies numerically with the temperature at which the measurement is made.

In many engineering applications, bulk density is expressed in pounds per cubic foot. One may convert from g. cm.$^{-3}$ to lb. ft.$^{-3}$ by multiplying by 62.4, the mass, in pounds, of a cubic foot of water at the temperature of its maximum density, i.e., 4°C.

30–2 CORE METHOD

30–2.1 Introduction

With this method, a cylindrical metal sampler is pressed or driven into the soil to the desired depth and is carefully removed to preserve a known volume of sample as it existed *in situ*. The sample is dried to 105°C. and weighed. Bulk density is the oven-dried mass divided by the field volume of the sample.

The core method is usually unsatisfactory if more than an occasional stone is present in the soil.

30–2.2 Method [2]

30–2.2.1 *SPECIAL APPARATUS*

Core samplers vary in design from a thin-walled metal cylinder to a cylindrical sleeve with removable sample cylinders that fit inside. A widely used and very satisfactory sampler consists of two cylinders fitted one inside the other. The outer one extends above and below the inner to accept a hammer or press at the upper end and to form a cutting edge at the lower. The inside cylinder is the sample holder. The inside diameters of the two cylinders when nested are essentially the same at the lower end, the inner being fitted against a shoulder cut on the inner surface of the outside cylinder. Figure 30–1 shows such a sampler (available in slightly different design from the Utah Scientific Research Foundation, Utah State University Campus, Logan, Utah).

[2] U. S. Dept. Agr. (1950, p. 121), Russell (1949), and Am. Soc. Testing Mater. (1958, p. 442).

Fig. 30–1. Typical double-cylinder, hammer-driven core sampler for obtaining soil samples for bulk density.

Numerous samplers have been described in the literature. Some of the more recent and accessible ones are described by Lutz (1947), Jamison et al. (1950), Baver (1956, p. 181), and U. S. Dept. Agr. (1954, p. 159).

30–2.2.2 PROCEDURE

The exact procedure for obtaining the samples depends on the kind of sampler used. The following steps apply when the widely known double-cylinder sampler is used.

Drive or press the sampler into either a vertical or horizontal soil surface far enough to fill the sampler, but not so far as to compress the soil in the confined space of the sampler. Carefully remove the sampler and its contents so as to preserve the natural structure and packing of the soil as nearly as possible. A shovel, alongside and under the sampler, may be needed in some soils to remove the sample without disturbance. Separate the two cylinders, retaining the undisturbed soil in the inner cylinder. Trim the soil extending beyond each end of the sample holder (inner cylinder) flush with each end with a straight-edged knife or sharp spatula. The soil sample volume is thus established to be the same as the volume of the sample holder. In some sampler designs, the cutting edge of the sampler has an inside diameter slightly less than the sample holder, so as to reduce

friction as the soil enters the holder. In these cases, determine the diameter of the cutting head and use this to calculate the sample holder volume. Transfer the soil to a container, place it in an oven at 105°C. until constant weight is reached, and weigh it. The bulk density is the oven-dry mass of the sample divided by the sample volume.

30–2.2.3 *COMMENTS*

It is often desired to make other measurements on the same samples taken for bulk density. Water content determinations, like bulk density, do not require that the soil be kept undisturbed during transport to the laboratory and drying. They do require a wet weight, however, so that the samples must be transported from field to laboratory in containers that do not permit loss of water. One-pint cylindrical waxed-paper cartons with lids will receive the 3-inch-diameter, 3-inch-long cylinders, and serve very well to transport the sample with almost no loss of water. Some studies, such as pore-size distribution, require that the sample be maintained as free of disturbance as possible.

Core samples should not be taken in wet or dry soils. In wet soils, friction along the sides of the sampler and vibrations due to hammering are likely to result in viscous flow of the soil and thus in compression of the sample. When this occurs the sample obtained is unrepresentative, being more dense than the body of the soil. Compression may occur even in dry soils if they are very loose. Whenever a sample is taken, one should carefully observe whether the soil elevation inside the sampler is the same as the undisturbed surface outside the sampler. One can only roughly estimate in this manner whether the density of the sample is changing because of sampling.

In dry or hard soils, another problem arises. Hammering the sampler into the soil often shatters the sample, and an actual loosening during sampling may occur. Samplers pressed into the soil usually avoid the vibration which causes this shattering. Close examination of the soil sample usually allows one to estimate whether serious shattering occurs. And, as in the case of wet soils, soil level inside and outside the sampler must remain the same if the sample is to be considered satisfactory.

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29 Particle Density[1]

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29–1 INTRODUCTION

Particle density of soils refers to the density of the solid particles collectively. It is expressed as the ratio of the total mass of the solid particles to their total volume, excluding pore spaces between particles. Units used are nearly always grams per cubic centimeter (g. cm.$^{-3}$).

Particle density is used in most mathematical expressions where volume or weight of a soil sample is being considered. Thus interrelationships of porosity, bulk density, and air space, and rates of sedimentation of particles in fluids depend on particle density. Particle-size analyses that employ sedimentation rate, as well as calculations involving particle movement by wind and water, require information on particle density.

29–2 PRINCIPLES

Particle density of a soil sample is calculated from two measured quantities, namely, mass of the sample and its volume. The mass is determined by weighing, the volume by calculation from the mass and density of water (or other fluid) displaced by the sample. This method has long been in use. It is simple, direct, and accurate if done carefully.

29–3 METHOD[2]

29–3.1 Special Apparatus

A pycnometer (specific-gravity flask) is employed. A pycnometer is a glass flask fitted with a ground glass stopper that is pierced lengthwise by

[1] Paper No. 4949 of the Scientific Journal Series, Minnesota Agr. Exp. Sta., St. Paul.

[2] Am. Soc. Testing Mater. (1958, p. 80) and U. S. Dept. Agr. (1954, p. 122).

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a capillary opening. A thermometer is sometimes an integral part of the stopper, the glass-enclosed mercury reservoir being in contact with the fluid in the flask, and the stem extending above the ground joint.

A small volumetric flask (25, 50, or 100 ml.) may be used in place of a pycnometer where the sample is large enough to compensate for the decrease in precision of measuring fluid volume.

29–3.2 Procedure

Weigh a clean, dry pycnometer in air. Add about 10 g. of air-dry soil. If a 100-ml. volumetric flask is used, add 50 g. of soil. Clean the outside and neck of the pycnometer of any soil that may have spilled during transfer. Weigh the pycnometer, including stopper, and its contents. Determine the water content of a duplicate soil sample by drying it at 105°C.

Fill the pycnometer about one-half full with distilled water, washing into the flask any soil adhering to the inside of the neck. Remove entrapped air by gentle boiling of the water for several minutes with frequent gentle agitation of the contents to prevent loss of soil by foaming.

Cool the pycnometer and its contents to room temperature, and then add enough boiled, cooled, distilled water at room temperature to fill the pycnometer. Insert the stopper, and seat it carefully. Thoroughly dry and clean the outside of the flask with a dry cloth. Weigh the pycnometer and its contents, and determine the temperature of the contents.

Finally, remove the soil from the pycnometer. Fill the pycnometer with boiled, cooled distilled water at the same temperature as before, insert the stopper, thoroughly dry the outside with a cloth, weigh the pycnometer and contents, and measure the temperature.

Calculate the particle density as follows:

$$D_p = \frac{d_w(W_s - W_a)}{(W_s - W_a) - (W_{sw} - W_w)}$$

where

d_w = density of water in grams per cubic centimeter at temperature observed,
W_s = weight of pycnometer plus soil sample corrected to oven-dry condition,
W_a = weight of pycnometer filled with air,
W_{sw} = weight of pycnometer filled with soil and water, and
W_w = weight of pycnometer filled with water at temperature observed.

29–3.3 Comments

The method is very precise if volumes and weights are carefully measured. A weighing error of 1 mg. on a 10-g. soil sample gives an error in

particle density of only 0.0003 g. cm.$^{-3}$. A weighing error of 10 mg. on a 30-g. sample gives a particle density error of 0.001 g. cm.$^{-3}$. Greater errors can result from lack of precision in the volume measurement. If W_{sw} is based on a volume that exceeds the volumetric flask marking by 0.2 ml. and W_w on a volume 0.2 ml. deficient of the marking, the compounded particle density error is 0.15 g. cc.$^{-3}$ on a 40-g. sample. The analyst should check the calibration marking on the flask, as well as his ability to measure a reproducible volume by making a number of weighings of water in the flask to be used preliminary to the analysis. In addition to weight and volume errors, one must assume some error due to nonrepresentative sampling.

It has long been observed that water gives higher density values for finely divided, active powders than do weakly adsorbed, i.e., nonpolar, liquids. One of the later papers with an excellent review of previous findings is that of Gradwell (1955). For soils, density values in water are greater by 0.01 to 0.03, but densities of clay fractions may be higher by 0.1 to 0.3 in water than in other liquids such as toluene, xylene, or carbon tetrachloride. The use of special liquids for determining particle density is probably necessary for highly accurate determinations on the more active clays or clay fractions. In fine-textured soils, the error is probably 1% or less and can be disregarded for most purposes.

This method for determining particle density does not give the average density of the particles because soils do not contain equal masses of particles of all densities represented. Rather, the values obtained are weighted with respect to the relative masses of the particles having the different densities. Day,[3] in pointing out this ambiguity, suggests that "harmonic mean particle density" might be a more specific designation than particle density.

The method is not suitable for determining the density of individual soil grains. Density of large particles, weighing at least 1 g., may be determined by weighing the suspended particle in air and when immersed in a fluid as described for bulk samples (section 30–4). Special balances, such as the Jolly balance or the Westphal balance, are designed for this purpose, and are widely used by geologists and mineralogists.

[3] Day, P. R. Personal communication.

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8 Physical Condition of Water in Soil[1]

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8–1 GENERAL INTRODUCTION

Soil is composed of three reasonably distinguishable phases: solid, liquid, and gas. The solid phase may be called the "matrix" because this phase usually controls the form or distribution in space of the other two phases. The solid structures of the plant might be similarly designated, because there is much interdependence in the soil-plant-water system, and a terminology suitable for use in both could be advantageous.

It seems likely that over most of the wetness range in which plant roots normally function, all the water in soil is more or less constrained by, and has its properties altered by, forces associated with the matrix. It may be that only in the larger pores of coarse soils that are relatively wet is there water present that is beyond the influence of the matrix and has the properties of water in bulk. An attempt to identify the properties of liquid water in bulk with the liquid or film phase in soil is a considerable step that must be cautiously approached if confusion is to be avoided. Take for example the concept of hydrostatic pressure that is so useful for water in bulk. So far as the writer knows, this property has never been measured for film water, where, near the matrix, the quantity may have a high positive value.

Figure 8–1 may help to clarify the principles involved in several of the soil-water measuring methods described in this chapter. At *A* in the figure an idealized micro-micro syringe is shown withdrawing water from the film phase. The needle connects bulk water in the syringe with the soil water. When water transfer ceases, the temptation to say that the pressures at the two ends of the needle are the same should be resisted. It can only be said that the attraction of film water by matric forces is counteracted by the pressure reduction that is registered in the example by the deflection

[1] Contribution from the U. S. Salinity Laboratory, Soil and Water Conservation Research Division, ARS, USDA, Riverside, Calif. in cooperation with 17 Western states and Hawaii.

of the elastic diaphragm that is shown attached to the syringe to serve as a pressure gauge.

Neglecting solute effects, the work required to extract unit amount of water from soil was called the capillary potential by Buckingham (1907). When expressed as work per unit volume, this has the physical dimensions of pressure and was identified by Gardner et al. (1922) with the pressure difference registered by the diaphragm in the figure.

This equivalent pressure, when measured with reference to the atmosphere, is negative and for convenience has long been called soil-moisture tension or soil suction. Since it arises from water binding by forces anchored to the matrix, it could appropriately be called matric suction.

A more realistic mechanism for extracting water from soil is illustrated at the right in Fig. 8–1, where the soil-water system is shown in contact with a membrane that is permeable to soil solution, i.e., water and solute, but not to the matrix. The water films on the soil matrix make contact through the pores in the membrane with bulk water beneath the membrane. Here again, the deflection of an elastic diaphragm is used to indicate the matric suction, i.e., the pressure difference between the gas phase in the soil and the bulk water on the opposite side of the membrane. This is the pressure difference that is registered by the vacuum gauge of a tensiometer.

Measurements made with the structures shown in the figure are little affected by solute in the soil-water system. However, when water is lost from soil by vaporization, or when water having a different solute content is extracted from the soil by plant root action, osmotic effects become operative, and water binding by solute should be taken into account. This water binding will here be designated by the term solute suction, which is a physical property numerically equal to osmotic pressure, but which has

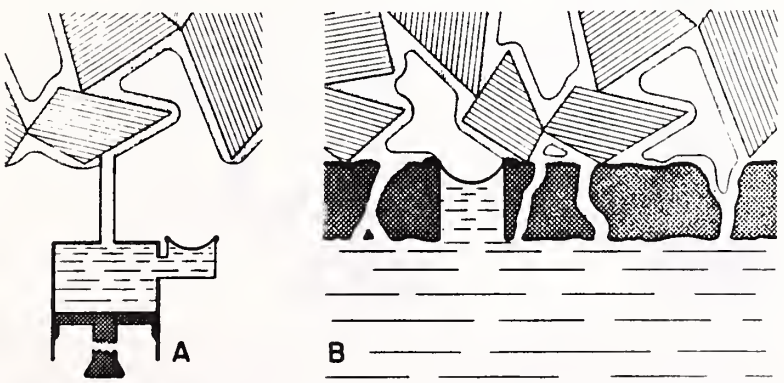

Fig. 8–1. Idealized mechanisms for visualizing the physical condition of water in soil. At *A* an idealized micro-micro syringe is shown connecting water in the film phase of the soil with water in bulk in the syringe. This is a "one-pore" equivalent of the permeable membrane shown at *B*. The deflection of the elastic diaphragm indicates that in each case the hydrostatic pressure of the bulk water is less than the pressure of the gas phase in the pore space of the soil.

opposite algebraic sense and therefore is directly additive and consistent with matric suction. The sum of matric suction and solute suction has been called total suction and has many of the advantages of a potential for expressing the energy condition of water in the soil-plant system without the disadvantage of the negative sign, which is inconvenient for some purposes.

For purposes of definition of these suction terms, consider the membrane system shown in Fig. 8–2, which is assumed to be at thermodynamic equilibrium under isothermal conditions. A chamber of wet soil at atmospheric pressure is shown in contact with "bulk" phases of water and soil solution through appropriate membranes. Matric suction is indicated by the middle manometer. In this case the soil, the permeable membrane, and the closed water system connected to a pressure indicator comprise a soil-water tensiometer. The reading of this instrument is little affected if the bulk solution in the instrument differs from the equilibrium dialyzate of the soil.

The left-hand (differential) manometer indicates solute suction, which is the equilibrium pressure difference across a semipermeable membrane separating soil solution (equilibrium dialyzate) from pure water. Solute suction is numerically equal to the osmotic pressure of the soil solution.

The right-hand manometer indicates the total suction of the solution in the soil. This is shown to be equal to the solute suction plus the matric

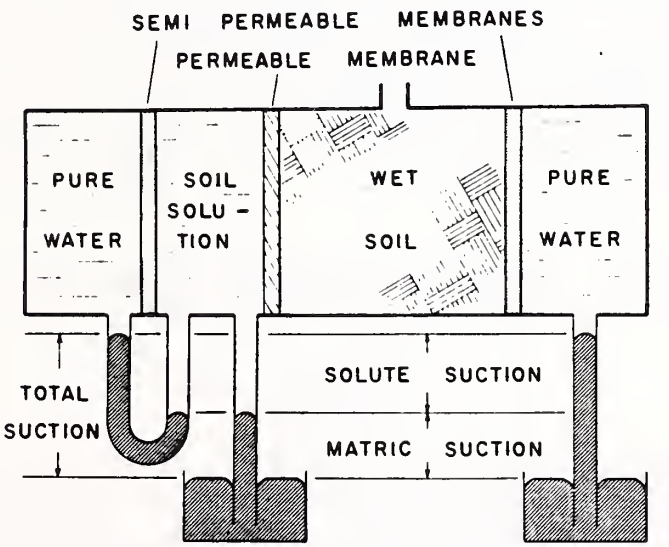

Fig. 8–2. In an isothermal equilibrium system, matric suction is the pressure difference across a membrane separating soil solution (equilibrium dialyzate) in bulk from soil containing the solution, the membrane being permeable to solution, but not to matrix or to mass flow of gas; solute suction is the pressure difference across a semipermeable membrane separating bulk phases of pure water and the soil solution; total suction is the sum of the matric suction and the solute suction and is the pressure difference across a semipermeable membrane separating pure water and soil that contains solution. An ideal semipermeable membrane is permeable to water only.

suction, and is the equilibrium pressure difference across a semipermeable membrane separating the solution in the soil from pure water.

Satisfactory membranes permeable to the soil solution are available and are commonly used for measuring or controlling matric suction, but the use of membranes to measure the solute and total suction of water in soil has not yet been successfully accomplished. Freezing-point depression measurements have long been used for evaluating solute suction (osmotic pressure) of bulk solutions, but uncertainties connected with the undercooling correction have made questionable the use of this measurement for evaluating the total suction of water in soil. It is possible now, however, by making use of another colligative property, the vapor-pressure depression, to measure matric, solute, and total suction of water in soil at any water content. For this measurement, the gaseous phase acts, in a way, like a membrane that is permeable to water but not to solute.

By use of thermocouple psychrometers, Richards and Ogata (1961, 1962) have shown, as predicted by theory, that a unit of matric suction produces the same vapor-pressure depression as a unit of solute suction. They showed also that thermodynamic equilibrium is readily attainable for soil samples on conventional pressure membranes. Saturated paste samples of soil at different salinity levels were brought to known matric suction values on pressure plates, and the total suction was then measured by the thermocouple psychrometer method. They found that for each sample, the total suction value was substantially equal to the sum of the matric suction plus the solute suction of the solution extracted from the saturated paste.

Methods are given in this chapter for evaluating the physical condition of water in soil by membrane, freezing-point depression, and vapor-pressure depression procedures.

8–2 WATER RETENTIVITY OF SOIL AT SPECIFIED VALUES OF MATRIC SUCTION

8–2.1 Introduction

The terms sorption and desorption, as applied to soil, usually refer to the processes of uptake and release of water. Sorption usually refers to a monotonically increasing water-content change, while desorption refers to the reverse process. Sorption and desorption data usually consist of equilibrium or steady-state values of water content of soil as related to some controlled physical property such as vapor pressure or matric suction. Expressed in terms of water content, the lagging of sorption values below desorption values is referred to as hysteresis.

Measurements of the sorption of gases and of the vapor of liquids on soil have yielded very useful information, and are the basis for specific sur-

face measurements, which are described in section 42. Measurement of soil hygroscopicity by sorption of water vapor was once popular; but, near the field wetness range, extreme care is required if this type of measurement is to be an index of a soil property that is independent of apparatus and procedure. The present section will deal with membrane measuring methods where matric suction is controlled.

8–2.2 Principles

The range of matric suction covered by membrane apparatus is limited to about 0.8 bar if the pressure in the soil air is atmospheric pressure and the pressure difference across the membrane is controlled by vacuum. This limitation is removed if means are provided for increasing the pressure of the gas phase of the soil as was done by S. J. Richards (1939). A pressure chamber containing a porous membrane, which in this case is a ceramic plate with a sheet-rubber backing, is shown at *A* in Fig. 8–3. A metal screen provides space under the plate for bulk water, which is kept at atmospheric pressure by the tabular connection to the outside. Another form of pressure membrane is shown at *B* in Fig. 8–3. Here, a cellulose acetate membrane is supported on a screen base that provides contact with bulk water at atmospheric pressure. When considerable shrinkage accompanies a decrease in the wetness of the soil, contact of the sample with the membrane can be maintained by an overlying diaphragm as shown.

The range of matric suction for pressure membranes is determined by

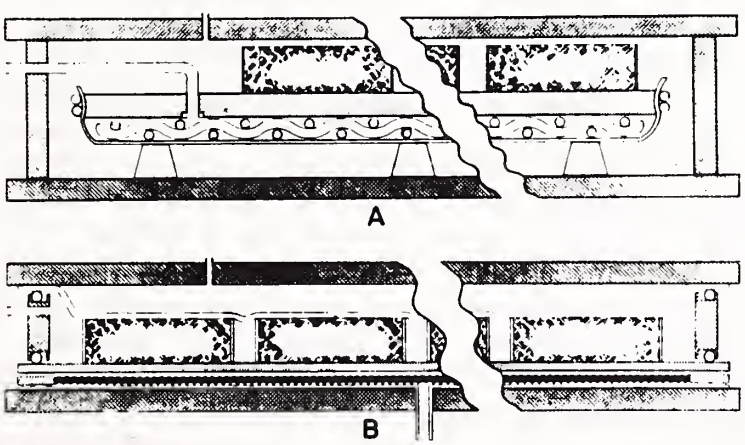

Fig. 8–3. *A*. Pressure plate apparatus in which the suction control "membrane" is a porous ceramic plate with a metal screen and sheet neoprene backing arranged to keep the lower side of the plate in contact with water at atmospheric pressure. (Not drawn to scale.) *B*. Pressure membrane apparatus with a typical arrangement for supporting a cellulose acetate membrane on a screen base. An overlying diaphragm may be used to hold the samples against the membrane. (Not drawn to scale.)

the safe working pressure of the chamber and the pressure difference the membrane will tolerate without allowing air to bubble through the pores. The bubbling pressure for some cellulose acetate membranes is about 150 bars, and ceramic membranes are available for use up to at least 15 bars. In addition to the bubbling-pressure requirement, the membrane must be permeable to water and to solutes in the soil, but not to matrix. Either organic or ceramic membranes may be used.

The hydraulic conductivity and hydraulic conductance of the membrane can be specified in terms of the conventional flow equation $v = ki$ (Richards, 1952) used for soil. Substituting $v = Q/TA$, $k = KL/A$, and $i = H/L$ gives $Q/T = KH$, where Q is the volume of water passing through a membrane of area A and thickness L in time T, H is the difference in hydraulic head of bulk water on the two sides of the membrane, and k and K are, respectively, the hydraulic conductivity and conductance of the membrane. For a pressure membrane with both sides in contact with bulk water and a pressure difference of P bars, we have for centimeter-gram-second (cgs.) units, $K = Q/1023\ TP$. Often the centimeters of water head per bar (1,023) is omitted, and the membrane conductance is expressed as cc. $min.^{-1}\ bar^{-1}$.

The apparatus, procedures and terminology relating the sorption and desorption of water by soil are far from stabilized. The wetness of soil at specified matric suction has been called retentivity. The temperature and air pressure at which the measurement was made, as well as some information on the structure or history of the sample, should be given whenever rententivity data are formally presented. The maximum-desorption curve, which starts at saturation and shows retentivity at progressively increasing suction values, is often called a water-retention curve. It seems likely that desorption processes in the field, especially under irrigation, are of longer duration than sorption processes. Possibly for this reason, retention curves are most often measured.

Sintered-glass filter funnels and specially mounted clay plates with controlled vacuum were used for early retention measurements. Some retention data have been obtained at low suctions by use of tension tables that are suitable for handling a considerable number of samples (Jamison and Reed, 1949). Unfortunately, few retentivity measurements have been published for soil samples with field structure. Measurements made with samples that have been dried, screened, and artificially packed should be applied with caution to field situations, especially at the wet end of the soil moisture range. Some retentivity data have been obtained by placing the cores directly in contact with the suction-control surface (Jamison, 1958). Ceramic, bottom-retainer plates have been proposed for this type of measurement (Richards, 1956). Special apparatus design is required to keep one side of the membrane in contact with bulk water if water uptake measurements are to be made (Tanner and Elrick, 1958).

The pore-space system of soil dominates water retention at low suctions. The dependence of pore space on bulk density and structure therefore emphasizes the need for samples with field structure if the wet end of the retention curve is of particular interest. Nevertheless, numerous retentivity values for air-dried and screened samples of soil have been measured at suctions of 0.1 and 0.33 bar because these measurements are easy to make, and correlations with other soil-water measurements were found (Richards and Weaver, 1944). The usefulness of these correlations, however, should be carefully scrutinized (Richards, 1960).

Toward the dry end of the wetness range found in the root zone of crops in the field, water retention is determined largely by the specific surface of the soil. Consequently, the preservation of field structure in water-retention samples is of relatively little concern at matric suction values above 1 or 2 bars. In the absence of direct methods for measuring soil suction above the tensiometer range, retentivity data have provided useful information. The 15-bar retentivity value, for example, has a reasonably close linear correlation with the permanent wilting percentage (Lehane and Staple, 1960).

8–2.3 Method [2]

8–2.3.1 SPECIAL APPARATUS

1. Membrane apparatus: Pressure-plate and pressure-membrane apparatus like those shown in Fig. 8–3 are commercially available and are usually about 28 cm. in diameter. Soil on the membrane is contained in rings of approximately 1-cm. height and 6-cm. diameter that hold about 25 g. of sample. Rubber rings must be used on acetate membranes.
2. Source of regulated air pressure: A source of compressed air at adjustable regulated pressure is required, such as that supplied by Soilmoisture Equipment Co., Santa Barbara, Calif.

8–2.3.2 PROCEDURE FOR TESTING APPARATUS

To check ceramic pressure-plate apparatus for defects, install the plates in the chamber, cover the plates with water, close the chamber, and apply the maximum appropriate air pressure. Measure the outflow rate as soon as the outflow becomes relatively free of air bubbles. Since this is a qualitative test, do not wait for a steady outflow rate. Commercial plates of approximately 28-cm. diameter, with 1- and 2-bar bubbling pressure, have a conductance of about 15 cc. $min.^{-1}$ bar^{-1}, while plates with 15-bar bubbling pressure have a conductance in the range of 0.5 to 2 cc. $min.^{-1}$ bar^{-1}. Plate conductance is not critical except for retentivity measurements at low suction values. In this case, higher conductance gives appreciably faster results.

[2] U. S. Salinity Laboratory Staff (1954).

Next check the plates for bubbling pressure. This is the pressure difference that will cause streaming of air through a wet plate. Release the air pressure, empty excess water from the chamber, and apply the maximum air pressure to be used in the retentivity measurements. After a few minutes, the outflow of water will cease, and there should ideally be no bubbling of air. Actually a bubbling rate as high as 2 or 3 cc. of air per minute can be tolerated. Air bubbling at the outflow tube can come through the plate, but it can also come from leaks in the mounting or from joints in the outflow tube that are inside the chamber.

After observing air bubbling at the outflow tube, submerge the chamber in water, or observe air pressure change in the chamber with the supply source shut off, to make sure the chamber is air-tight. Air leaks from the chamber may produce evaporative losses that will dry the samples below the equilibrium value that would otherwise have been attained by membrane suction.

8–2.3.3 PROCEDURE FOR RETENTIVITY MEASUREMENTS

It is convenient to have 75 to 100 g. of air-dried soil. Reduce all aggregates to <2-mm. diameter by rubbing the soil through a 2-mm. round-hole sieve with a rubber stopper. Place the sieved fraction on a mixing cloth, and pull the cloth in such a way as to produce mixing. (Some pulling operations will produce segregation instead of mixing, and special care must be exercised to obtain a homogeneous sample.) Flatten the sample until the pile is 2 to 4 cm. deep.

For water retentivity, two or three representative subsamples having a fairly definite volume are required. Use a separate paper cup for each subsample. Mark with a pencil line around the inside of the cup the height of soil needed to give the desired volume of subsample. This volume should be somewhat less than the volume of soil required to make the soil-retainer ring on the membrane level full. Use a thin teaspoon or scoop (not a knife or spatula), and lift small amounts of soil from the pile. Place successive spoonfuls in successive cups, and progress around the pile until the cups are filled to the desired level. Transfer a small enough quantity of soil in each operation to keep the larger particles from rolling off the spoon or scoop. Roll-off should be avoided because it makes the extracted subsample nonrepresentative. Place the sample-retainer rings on the porous plate. To avoid particle-size segregation, dump *all* the subsample from each container into a ring, and level the soil without spilling any outside the ring. A wide-mouth powder funnel, used as a tremie, is convenient for this sample transfer operation. Allow the samples to stand at least 16 hours with an excess of water on the membrane. Close the pressure chamber, and apply pressure. Connect the outflow tube from the pressure chamber to the bottom of a 25- or 50-ml. buret.

For a pressure chamber with an acetate membrane and a rubber dia-

phragm for holding the samples against the membrane, proceed as follows: Apply the air pressure first to the soil chamber. After a short time, usually 1 or 2 hours, the water outflow rate falls off markedly. By this time, the wet samples acquire some bearing strength. Then apply an excess of pressure of about 1/4 bar to the diaphragm chamber in accordance with the manufacturer's instructions.

Samples 1-cm. high can be removed any time after 48 hours from initiating the extraction or when readings on the outflow buret indicate that liquid water outflow has ceased from all samples on each membrane. Some soils will approach equilibrium in 18 to 20 hours. Before releasing the air pressure in the chamber, put a pinch clamp on the outflow tube. This reduces backflow of water to the samples after the pressure is released. To avoid changes in the water content of the samples after opening the chamber, transfer the samples quickly to metal boxes for drying. Determine the water content by drying the samples to constant weight at 105°C. Express the water content in terms of percentage on a dry-weight basis. Retentivity data should be accompanied by information on the temperature and ambient air pressure of the soil while on the membrane. Information on the structure and history of the sample should also be given.

8–2.3.4 COMMENTS

For some purposes, the ratio R of the weight of the coarse separate (>2 mm.) to the weight of the fine separate ($\leq$2 mm.) should be recorded. Mineral soil material >2-mm. diameter complicates retentivity measurements and retains a negligible amount of water. When desired, the retentivity of the whole soil P_W can be calculated from the retentivity of the fine separate P_F by the equation, $P_W = P_F[1/(1 + R)]$.

Some air transfer always occurs through wet pressure membranes. According to Henry's law, the solubility of air in water is proportional to the pressure. Consequently, the concentration of dissolved air in the membrane water on the soil side is always higher than on the outflow side. This air moves through the membrane during liquid outflow and appears as bubbles in the outflow buret. When liquid outflow ceases, dissolved air moves through the membrane by molecular diffusion, and air bubbles will continue to appear in the outflow system, but at a reduced rate. This may amount to several cubic centimeters per minute for Visking cellulose membranes, 28 cm. in diameter, at a pressure of 15 bars. The maximum possible error from this air transfer can be calculated by assuming that all the water required to humidify these air bubbles comes from the soil samples.

The time required for soil samples to attain hydraulic equilibrium with a membrane increases approximately with the square of the height of the sample. This should be taken into consideration if it is planned to put core samples on a membrane.

Ceramic plates with rubber backing for use in pressure chambers up to

15 bars are less troublesome to use than cellulose membranes. Microbial action in some soils, iron rust from the chamber, sand grains near the gasket seal, and other things can cause disabling leaks in cellulose membranes. Pressure chambers for acetate membranes, however, do have the diaphragm for pressing the sample against the membrane to prevent loss of contact that might be caused by shrinkage of fine-textured samples.

Principal errors in retentivity measurements come from nonrepresentative subsamples; evaporative loss from samples during approach to equilibrium, as occurs on tension tables, or as caused by air leaks from pressure chambers; pressure or temperature fluctuations causing hysteresis effects; failure to attain outflow equilibrium; inadequate prewetting of samples; wetting of samples from backflow; or drying by evaporation during removal of the samples from the membrane. With skill, a coefficient of variation of 1 or 2% is attainable, and the measured value is independent of the type of apparatus or membrane.

SOP 9
FIELD SATURATED AND UNSATURATED HYDRAULIC CONDUCTIVITY

Background:

Data on saturated and unsaturated water flux are important design criteria for development of remedial alternatives. While a number of methods are available for measurement of unsaturated hydraulic conductivity, most field methods (instantaneous profile method, gypsum crust method) are time-consuming and are not easily replicated. Laboratory methods do not always provide an accurate assessment of field conditions due to sample disturbance and small sample size. Recently, a constant head device for measurement of hydraulic conductivity in the field was developed at the University at Guelph. The "Guelph Permeameter" marketed by Soil Moisture Equipment Company is a constant head permeameter capable of providing a measure of conductivity in 2 hours or less. The speed of the measurements provided by the device allows for replication of measurements thus providing a measure of precision or spatial variability of conductivity.

The Guelph Permeameter measures the field-saturated hydraulic conductivity, sorptivity (dependent on matric potential), and the slope of the equation developed to predict unsaturated hydraulic conductivity from field-saturated K:

K(unsat) = K(fs) exp (A * Water Potential)

The coefficient (A) is determined by the results provided by the Permeameter.

Description of Method:

At each sample location described in the TSOP, at least one measurement of unsaturated hydraulic conductivity will be made. Replicate measurements will be performed at the rate of 1 in 10. All readings will be made in accordance with manufacturers recommendations provided in Appendix C. A method for permeameter testing of saturated hydraulic conductivity (ASA 1965) is attached. This method has been modified by development of the Guelph permeameter.

METHODS OF SOIL ANALYSIS

Part 1

Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling

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1965

15–4 PERMEAMETER METHOD

15–4.1 Principles

The permeameter method, also referred to as the cylinder permeameter method, is based on the measurement of the rate of outflow of water supplied to an auger hole above the water table.

A hole of large diameter is dug as shown in Fig. 15–10. At the center of the hole is placed a cylindrical sleeve 45 cm. in diameter. The sleeve is made to penetrate the soil 15.24 cm. below the bottom of the hole. The same water level is maintained inside and outside the cylinder, and the rate of water intake from the inside cylinder is measured. The hydraulic conductivity in the vertical direction can be calculated if the pressure near the bottom edge of the cylinder is known. The pressure near the bottom edge of the cylinder is measured with tensiometers. When the tensiometers indicate zero tension, saturation is assumed. Build-up of positive pressures is registered by the tensiometers. No measurements should be made after positive pressures have developed. Hydraulic conductivity is calculated with Darcy's law: $K = QL/HA$, where Q is the rate of flow, H is the pressure difference across the soil column inside the cylinder, L is the height of the soil column inside the cylinder, and A is the cross sectional area of the soil column inside the cylinder.

15–4.2 Method [1]

15–4.2.1 SPECIAL APPARATUS

A schematic diagram of apparatus for a permeameter test installation is shown in Fig. 15–10.

1. Head tank: Use a 200-liter tank calibrated in cubic centimeters, with zero marking at the top.
2. Wooden platform to keep head tank off the ground to prevent rusting.
3. Steel pipe, 2.5 cm. in diameter and 125 cm. long to be driven into the ground to keep the tank secured in place.

[1] Winger (1960).

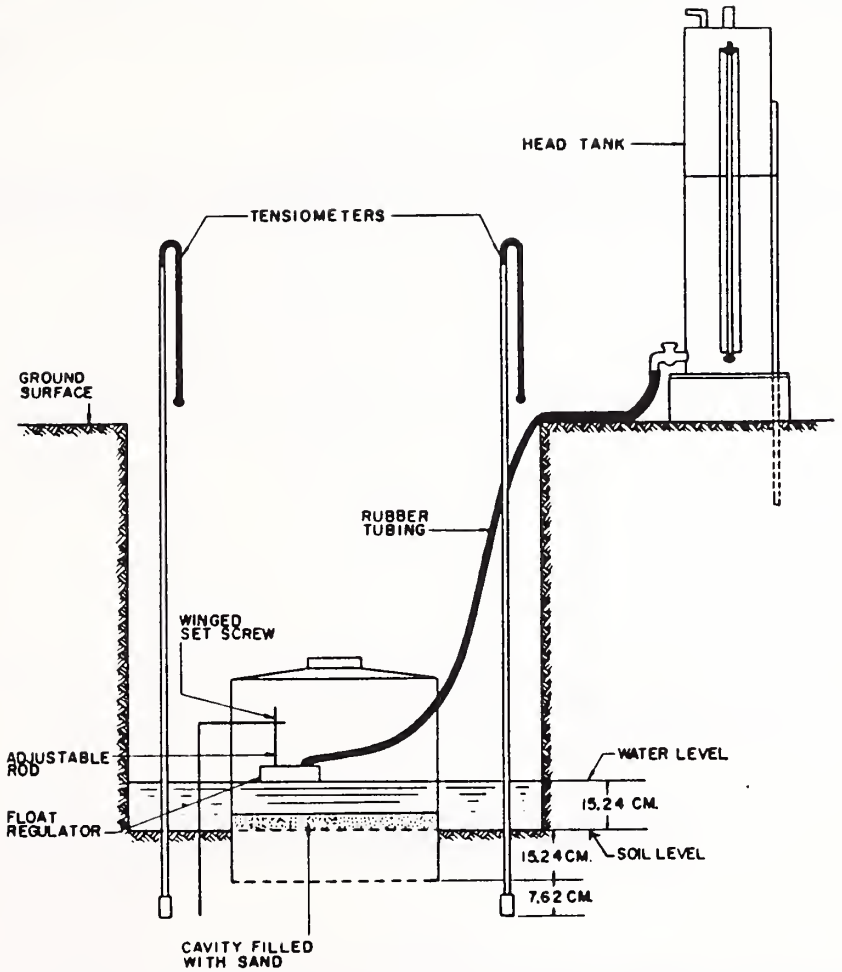

Fig. 15–10. Schematic diagram of equipment for the permeameter method in place.

4. Cylinder: 14-gauge steel with an inside diameter of 45 cm. and a height of 50 cm. with a reinforced band on top and a sharpened edge on the bottom, and with the welded seam ground down flush.
5. Constant-level float-valve made from old cut-down carburetor.
6. Tubing: Use rubber tubing with an inside diameter of 1 cm. to connect the head tank to the constant-level float-valve.
7. Adjustable rod to hold the constant-level float-valve at the desired elevation.
8. Threaded bolt which fastens to the steel cylinder and supports the adjustable rod to hold the float-valve at the desired elevation.
9. Tensiometers: Use four mercury tensiometers with a length of 50 cm. and an inside diameter of 1 cm. and with construction such that positive as well as negative pressures can be registered.

AGENCY
DEPARTMENT
OBSERVER

LOCATION
HOLE NO
DATE

DATA AND CALCULATIONS

INITIAL		FINAL		TIME	TANK READING cc		VOLUME	Q	TEMP OF WATER °C	VISCOSITY OF WATER CENTIPOISES	ADJUSTED Q	HYDRAULIC CONDUCTIVITY	TENSIOMETERS			
DATE	TIME	DATE	TIME	HRS	INITIAL	FINAL	CC	CC/HR			CC/HR	CM/HR	1	2	3	4
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17

$K = (Q/A) \times (L/H)$

Q = CC/HR
A = CM^2
T = HRS.
L = CM
H = CM
K = CM/HR

NOTES

Fig. 15–11. Suggested field sheet for use with the permeameter method.

10. Driving equipment for cylinder and piezometers.
11. Water-supply tank truck of at least 1,500-liter capacity.
12. Tiling spade.
13. Steel tape.
14. Bentonite to seal around tensiometers.
15. Washed sand passing the No. 14 sieve and retained on the No. 28 sieve.
16. Carpenter level.

15–4.2.2 PROCEDURE

Prepare a set of data sheets such as shown in Fig. 15–11 for recording measurements and for calculations.

Excavate a hole 1 m. square to the layer to be tested, and level an area 45 cm. square in the center of the hole. Check the level with a carpenter level, and be sure not to walk in this area. Drive the test cylinder 15 cm. into the soil of the leveled area. Keep the cylinder level during the operation, and direct the blows straight down to avoid disturbance of the natural profile. Tamp the soil against the cylinder wall on the inside as well as on the outside to avoid channeling of the water along the sides. Against the inside wall, tamp the soil only lightly and only close to the wall. Spread about 2 cm. of uniform coarse sand over the area inside the cylinder to avoid puddling of the soil surface during the test.

Space the four calibrated tensiometers at equal intervals around the outside cylinder, each 10 cm. outside the cylinder and 23 cm. below the level of the soil inside the cylinder. Make sure that good contact is obtained between the porous cup and the soil. Tamp a 50:50 bentonite-soil mixture around the tensiometer to avoid channeling of water along the sides. Install the constant-level float-valve in the cylinder, and adjust it to maintain a constant 15-cm. head. Put the calibrated supply tank in place, anchor it securely, and connect it to the constant-level float-valve; then fill the cylinder with water 15 cm. deep, and open the float-valve. Fill the hole outside the cylinder with water to a depth of 15 cm., and maintain the water level at approximately this depth during the test period.

Record the time and the reading on the supply-tank gauge. Also record the readings on the tensiometers. Continue the test by recording the time, supply-tank gauge reading, tensiometer readings, amount of water added and water temperature at regular intervals. The intervals should be short enough so that the supply tank never runs dry. Terminate the test when the tensiometers indicate zero tension, and the water is moving through the 15-cm. test layer at a constant rate. At this time it is assumed that the requirements for the use of Darcy's law are met.

Compute the flow rate each time the site is visited. Compute all flow rates for a temperature of 20°C., making corrections for viscosity effects by multiplying the calculated flow rate by the ratio of the viscosity of water at the temperature during the period of measurement to the viscosity of water at 20°C. Calculate the hydraulic conductivity from Darcy's law, $K = QL/AH$, where K is hydraulic conductivity, Q is the flow rate, A is the cross-sectional area of the cylinder, L is the length of the soil column inside the cylinder, and H is the height of the water level inside the cylinder above the base. Calculations can be performed on the data sheet shown in Fig. 15–11.

15–4.2.3 COMMENTS

The cylinder permeameter method permits measurement of the vertical component of hydraulic conductivity of restricting or slowly permeable layers that obstruct percolation and cause perched water tables.

A limitation of the method is that positive pressures may develop when the horizon being tested is underlain by a layer of lower hydraulic conductivity or is close to a water table. In the presence of positive pressures indicated by the tensiometers, the test will no longer give a true value of the hydraulic conductivity. Winger (1960) suggested that it might be possible to discharge the positive pressure by augering a number of holes around the outside of the cylinder approximately 10 inches away from it. Another situation under which conditions necessary for the calculation of the hydraulic conductivity are difficult to meet arises when the test zone is above a deep, very permeable material. A steady flow rate can be obtained, but the tensiometers will never indicate zero tension below the test zone. A further limitation is that the method cannot be used in rocky or coarse gravel material.

The method, although relatively easy to use, requires large quantities of water, is time consuming, and requires a great deal of specialized equipment.

SOP 10
TEMPE CELL COLUMN EXTRACTION METHOD

TEMPE cells are described in detail in Appendix C. They will be used to collect leachate from amended mine waste samples under partially saturated conditions.

Description of Method:

Amended mine wastes will be brought to the saturation point and placed in the cleaned TEMPE cell (see decontamination section below). The TEMPE assembly will be weighed, and the weight recorded on custom forms, shown in Appendix B. The assembly will be pressurized to 0.2 bars using a regulated pressure source, a mercury manometer for pressure measurement, and a manifold to control multiple cells. Leachate will be collected in cleaned beakers, and volume, pH, and EC measured immediately. The leachate will then be filtered and acidified with 1 ml of 1:1 HNO_3.

Five leachates samples will be submitted for laboratory analysis cooresponding to roughly 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 2.0, and 2 to 4 pore volumes of leachate. These volumes should correspond to 1, 2, 3, 4 to 8, and 9 to 16 extraction cycles. The last two samples will consist of composites of several extraction cycles. All requisite sample information will be recorded on the appropriate forms.

Soil Sample Analysis:

After the column extraction cycle is completed, the moist soil sample will be placed in an IChem jar, sealed, and submitted for analysis of soluble and extactable metals and other parameters outlined in the text. These samples shoulod not be allowed to dry.

Decontamination:

The TEMPE cell will be cleaned with soap (P-free) and water to remove adhering soil, and then three batches of 50 ml of 1:10 HNO_3 will be added and pushed through the cell using 0.2 bars of pressure. The acid rinses will be followed by three 50 ml rinses of disilled water. In 1 of twenty cycle runs, the third distilled water rinse will be submitted as a cross-contamination blank. Stainless steel or teflon cylinder rings will be substituted for the brass rings supplied with the TEMPE cells to avoid contamination.

SOP 11
CARWA EXTRACTION METHOD

The Computerized Automated Rapid Weathering Apparatus (CARWA) will be used to extract leachate from amended mine wastes. Results obtained from the CARWA will be used to collaborate those obtained from TEMPE cells.

Description of Method:

The CARWA consists of a three-chambered box (Appendix C) with spray nozzles and fans in the top and extraction screens in the base. A 200 gram mine waste sample will be amended and then placed in a sample chamber. Two hundred ml of distilled/deionized water will be sprayed into each chamber. The chambered box is then mechanically agitated until the mine waste solution is completely mixed. Vacuum suction is used to extract excess solution into individual holding chambers. The mine wastes are aerated by the overhead fans to promote oxygenation. The extracted solutions are discharged from the columns to clean beakers on a turntable and the next cycle begins. Six weathering cycles will be run on each amended mine waste sample. The individual length and sequence of each extraction cycle is controlled by a Z80 Sinclair microprocessor programmed in Basic.

Weathered Tailings analysis:

After the sixth weathering cycle, the moist mine waste material will be removed from the CARWA chambers and sealed in IChem jars. Laboratory analysis of CARWA weathered samples will follow the same procedures used for TEMPE leached mine wastes (SOP-10)

Decontamination:

The weathering chambers will be cleaned with P-free soap and water to remove adhering soil. Distilled, deionized water will be used to rinse the chambers. Once clean, three 100 ml rinses of 1:10 HNO3 will be added to the chambers and cycled through the holding columns, sprayers, and extraction screens to acid-rinse the system. Three 100 ml rinses of distilled/deionized water will be cycled through the system. The third distilled water rinsate following every twentieth mine waste sample will be collected as a cross-contamination blank.

APPENDIX B
STANDARD FORMS

SOIL pH AND EC DATA FORM
SITE DESCRIPTION FORM
HORIZON DESCRIPTION FORM
DAILY SITE CONDITION/ACTIVITY FORM
COLUMN PROCEDURE FORM
INORGANIC TRAFFIC REPORT FORM
CHAIN-OF-CUSTODY RECORD
SAS PACKING LIST
EPA TAG
CUSTODY SEALS
SAMPLE IDENTIFICATION MATRIX
RAPID CARRIER FORM

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WATER pH AND SC DATA FORM

JOB SITE ID : PAGE NO.:
FIELD TEAM MEMBERS :

DATE :
COMMENTS:

ENTRY NUMBER	MATRIX TYPE	STATION LOCATION	SAMPLE TYPE	TAG NUMBER	MEASURED pH	SC mmhos/cm
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						

MATRIX : L = LYSIMETER, IR = IRRIGATION/RUNOFF

LOCATION: ie. RF15 = RAMSAY FLATS SAMPLE 15. THESE SHOULD MATCH THE STATION LOCATION ON THE SAMPLE ID MATRIX FORM

TYPE : N = NATURAL SAMPLE, R = REPLICATE, CCB = CROSS-CONTAMINATION BLANK, BB = BOTTLE BLANK, BFS = BLIND FIELD STANDARD

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Bozeman, MT 59715
(406) 587-3478

Waste Management
Land Reclamation
Resource Inventory
Agricultural Consulting

SITE DESCRIPTION

PEDFORM Coding Form - Soil Profile Description Site Information

SOIL SERIES: SITE NUMBER: COUNTY:

LOCATION:
CLASSIFICATION:
DATE SAMPLED: ELEVATION: (FT or M) PRECIPITATION: (IN or MM)

MATERIAL	VEGETATION	LAND USE
01 volcanic ash	01 mixed coniferous	01 commercial forest
02 loess	02 ponderosa pine	02 non-commercial forest
03 glacial outwash	03 lodgepole pine	03 forest
04 glacial till	04 spruce-fir	04 range
05 lacustrine	05 larch-fir	05 dryland crop
06 peat	06 Douglas fir	06 irrigated crop
07 muck	07 mixed deciduous	07 irrigated hay
08 residual sandstone	08 cottonwood	08 dryland hay
09 residual shale	09 aspen	09 pasture
10 residual siltstone	10 trees	10 residential
11 residual limestone	11 dryland crop	11 urban
12 residual crystalline	12 irrigated field crop	12 disturbed land
13 mixed alluvium	13 row crops	13 strip mine
14 alluvium	14 horticultural crop	14 mill tailings
15 colluvium	15 riparian	15 mine dump
16 soliflucate	16 mixed shortgrass	16 wildland
17 sandstone alluvium	17 mixed midgrass	17 landfill
18 shale alluvium	18 shrubs and grasses	18 subirrigated hay
19 siltstone alluvium	19 halophytic	
20 crytalline alluvium	20 sedges and rushes	
21 limestone alluvium	21 perennial forage	
22 tailings	22 tame pasture	
	23 bare ground	
	24 dead litter	

DRAINAGE	PERMEABILITY	EROSION
01 very poor	01 very slow	01 none
02 poor	02 slow	02 slight
03 somewhat poor	03 moderately slow	03 moderate
04 moderately well	04 moderate	04 severe
05 well	05 moderately rapid	05 slight - wind
06 somewhat excessive	06 rapid	06 moderate - wind
07 excessive	07 very rapid	07 severe - wind
08 altered, drained		
09 altered, wetted		

SLOPE: deg, % ASPECT: SOIL TEMP (50 cm): F C

LANDSCAPE POSITION	LANDFORM		NUMBER HORIZONS:
01 crest	01 sed. upland	10 floodplain	---------
02 ridge	02 mountains	11 plateau	
03 upper midslope	03 playa	12 mudflow	
04 midslope	04 allvl. fan	13 patterned ground	
05 lower midslope	05 sand dune	14 backswamp	
06 footslope	06 outwash	15 landslide	
07 level slope	07 ground morrain	16 badlands	
	08 alpine till	17 disturbed land	
	09 terrace	18 talus	

COMMENTS:

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HORIZON DESCRIPTION

PEDFORM Coding Form - Soil Profile Description Horizon Data

SITE NUMBER: HORIZON NUMBER:

HORIZON DESIGNATION: START DEPTH: (cm) END DEPTH: (cm)

MOIST COLOR: DRY COLOR: COARSE FRAGMENTS: (%)

TEXTURE

01 s	17 fs
02 ls	18 vfs
03 lfs	19 si
04 lvfs	20 sndy
05 sl	21 co-lo
06 fsl	22 co-si
07 vfsl	23 fi-lo
08 l	24 fi-si
09 sil	25 fine
10 scl	26 very fine
11 cl	27 s. skl.
12 sicl	28 l. skl.
13 sc	29 c. skl.
14 c	30 frag.
15 sic	31 ashy
16 cos	32 medial

STRUCTURE

GRADE	SIZE	KIND
01 massive	01 massive	01 massive
02 weak	02 v. fine	02 platy
03 wk-mod.	03 fine	03 gran
04 mod.	04 med.	04 sbk
05 mod-strg	05 coarse	05 abk
06 strong	06v.coarse	06 prism
		07 clmnr.
		08 wedge

CONSISTENCE

DRY	MOIST	STICKY	PLASTIC
01 loose	01 loose	01 non	01 non
02 soft	02 v. fri.	02 slt.	02 slt.
03 s.hard	03 fr.	03 sticky	03 plastic
04 hard	04 firm	04 v.stky	04 v.plstc
05 v.hard	05 v.firm		
06 ex.hrd	06 ex.firm		
07 indurated			

ROOTS

NUMBER	SIZE	LOCATION
01 none	01 none	01 none
02 trace	02 fine	02 thru-out
03 few	03 f/vf	03 between peds
04 few-com	04 fine	04 cracks
05 common	05 med/f	05 near rocks
06 com-mny	06 medium	06 mat at top
07 many	07 co/med	
	08 coarse	

PORES

NUMBER	SIZE	KIND
01 none	01 none	01 none
02 trace	02 v.fine	02 irreg.
03 few	03 f/vf	03 tubular
04 few-com	04 fine	04 tub. continuous
05 common	05 med/f	05 tub. discont.
06 com-mny	06 medium	06 vesicular
07 many	07 co/med	07 tub. & tubular
	08 coarse	08 interstitial between rocks

pH: _____

EFFERVESCENCE

01 non calcareous
02 slight
03 moderate
04 violent

BOUNDARY

DISTINCTNESS	SHAPE
01 abrupt (<1")	01 smooth
02 clear (1-2.5")	02 wavy
03 gradual (2.5-5")	03 irregular
04 diffuse (>5")	04 broken
05 arbitrary	
06 not reached	

COMMENTS:

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DAILY SITE CONDITIONS / WORK DESCRIPTION FORM

SITE / PERSONNEL DATA:

SITE ID : _____ PAGE : ____ OF ____

ARRIVAL TIME : _____ DEPARTURE TIME : _____

LOCATION : _____ DATE: / /

PERSONNEL: _____

WEATHER:

WIND SPEED : _____ WIND DIRECTION: _____

PRECIPITATION TYPE: _____ AMOUNT : _____

CLOUD COVER : _____ TEMPERATURE : _____

CREEK LEVEL / APPEARANCE : _____

COMMENTS:

WORK ACCOMPLISHED : _____

_____

_____

DEVIATIONS FROM SOP´S : _____

_____

_____

CONTACTS : _____

_____

GENERAL COMMENTS : _____

_____

_____

_____

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Waste Management
Land Reclamation
Resource Inventory
Agricultural Consulting

TEMPE CELL DATA SHEET

TEMPE CYCLE INFORMATION

Technician:
Date : __/__/__ Time :
TEMPE cell number :
Soil Sample Name :
Amendment :
TEMPE tare wt. (g):
Initial wt. (g) : Initial time:

LEACHATE SAMPLE INFORMATION

Cycle#	Time start:stop	Vol Ext. (ml)	Tempe cell wt.(g)	pH	E.C.	Filt. Time	Acid-ified	EPA#	ITR#	Comments
QA/QC										
Calibration (pH)		-	-			-	-	-	-	
Calibration (EC)		-	-			-	-	-	-	
Standard (pH)		-	-			-	-	-	-	
Standard (EC)		-	-			-	-	-	-	
Metal std.			-	-	-					
Rinsate blank										
NATURAL LEACHATE CYCLE NO.										
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
13										
14										
15										
16										

* Each run is adjusted to initial assemble weight by addition of water.

LEACHED SOIL SAMPLE INFORMATION

Soil Sample #	EPA Tag #	ITR Tag #	Date	Time
Natural:				
Rep:				

COMMENTS:

U.S. ENVIRONMENTAL PROTECTION AGENCY / NWI Sample Management Office
INORGANICS TRAFFIC REPORT
Sample Number MHA 434

① Case Number:
Sample Site Name/Code:

② SAMPLE CONCENTRATION (Check One)
— Low Concentration
— Medium Concentration

③ SAMPLE MATRIX (Check One)
— Water
— Soil/Sediment

④ Ship To:

Attn:

Transfer Ship To:

⑤ Sampling Office:

Sampling Personnel:

(Name)

(Phone)

Sampling Date:

(Begin) (End)

⑥ Shipping Information:

Name Of Carrier:

Date Shipped:

Airbill Number:

MHA 434 -Task 1 & 2

MHA 434 -Task 1 & 2

⑦ Sample Description: (Check One)
— Surface Water
— Ground Water
— Leachate
— Mixed Media
— Solids
— Other (specify)

MATCHES ORGANIC SAMPLE NO.

⑧ Mark Volume Level On Sample Bottle
Check Analyses required
— Task 1 & 2
— Task 3 Ammonia
Sulfide
Cyanide

MHA 434 -Task 3

MHA 434 -Task 3

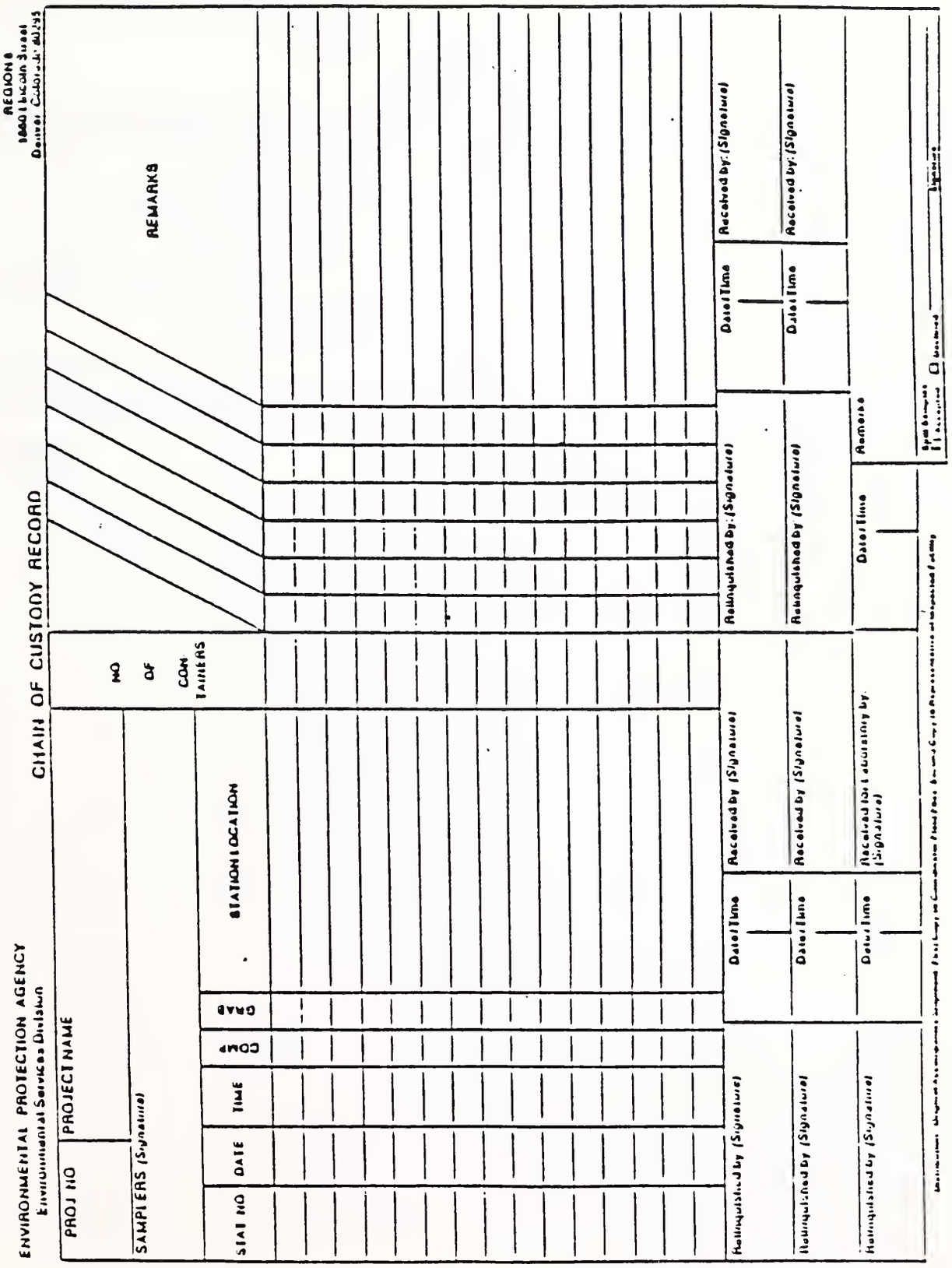
MHA 434 -Task 3

MHA 434 -Task 3

SMO COPY

INORGANIC TRAFFIC REPORT

SILVERBOW CREEK, MT RI/FS



CHAIN OF CUSTODY RECORD

SILVERBOW CREEK, MT RI/FS

U.S. ENVIRONMENTAL PROTECTION AGENCY
CLP Sample Management Office
P.O. Box 818 - Alexandria, Virginia 22313
Phone: 703/557-2490 - FTS/557-2490

SAS Number

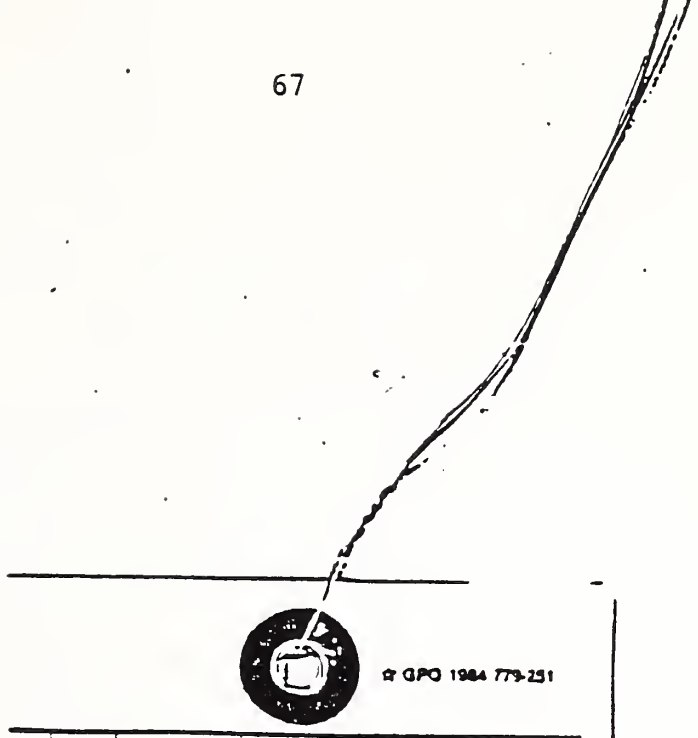
SPECIAL ANALYTICAL SERVICE
PACKING LIST

Sampling Office:	Sampling Date(s):	Ship To:	For Lab Use Only
Sampling Contact: (name)	Date Shipped:		Date Samples Rec'd:
(phone)	Site Name/Code:	Attn:	Received By:

	Sample Numbers	Sample Description- Le., Analysis, Matrix, Concentration	Sample Condition on Receipt at Lab
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
15.			
16.			
17.			
18.			
19.			
20.			

For Lab Use Only

White - SMO Copy, Yellow - Region Copy; Pink - Lab Copy for return to SMO, Green Lab Copy

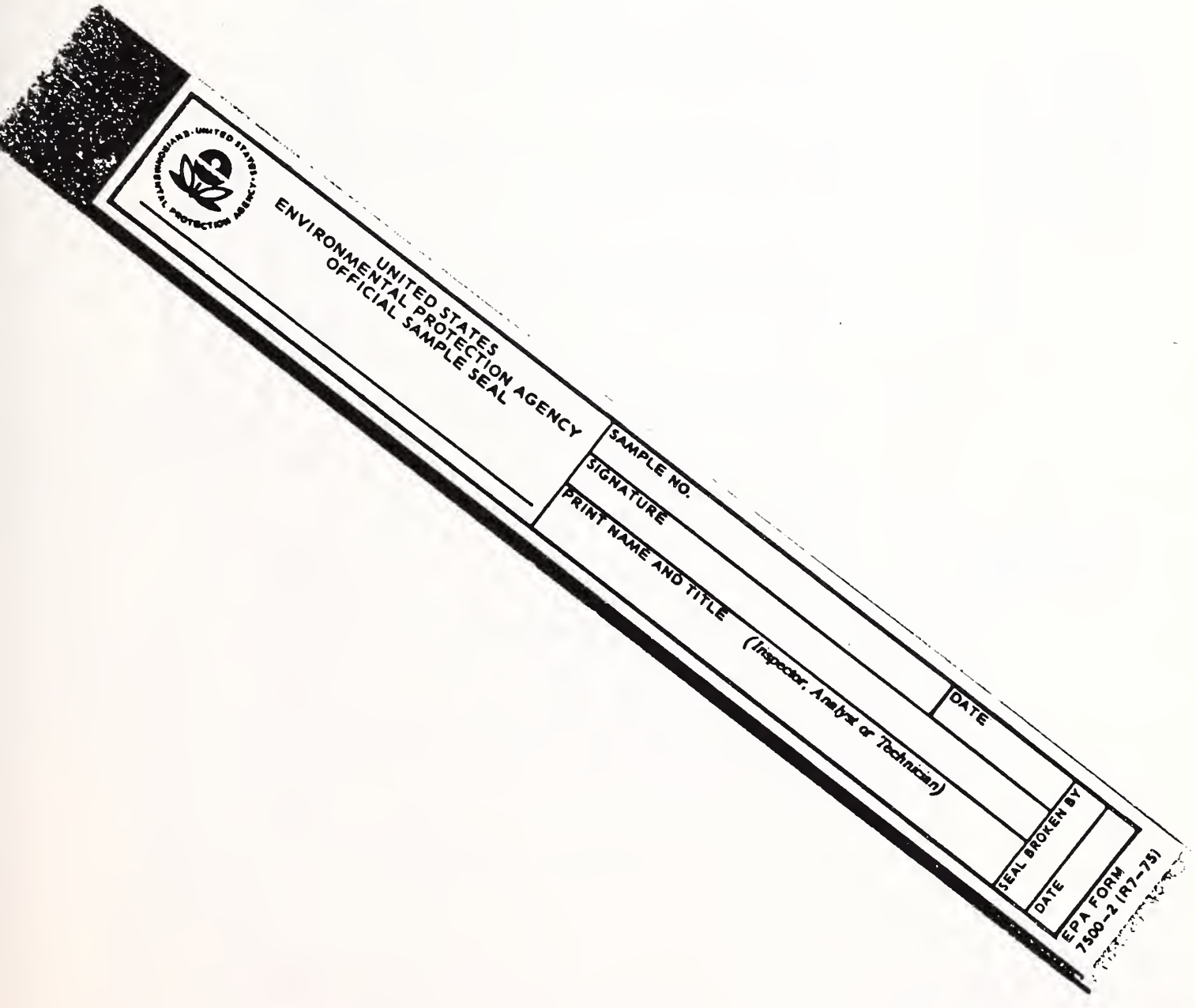


☆ GPO 1984 779-251

Designate: Grab / Comp	Samplers (Signatures)	Preservative: Yes ☐ No ☐	
		ANALYSES	
Time		BOD Anions Solids (TSS) (TDS) (SS).	
		COD. TOC. Nutrients	
		Phenolics	
		Mercury	
		Metals	
		Cyanide	
Month/Day/Year		Oil and Grease	
		Organics GC/MS	
		Priority Pollutants	
		Volatile Organics	
		Pesticides	
Station No.		Mutagenicity	
		Bacteriology	
Project Code	Station Location	Remarks:	
	Tag No. 8-12249	Lab Sample No.	

EPA SAMPLE TAG

SILVERBOW CREEK, MT RI/FS


UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
OFFICIAL SAMPLE SEAL
SAMPLE NO.
SIGNATURE
PRINT NAME AND TITLE (Inspector, Analyst or Technician)
DATE
SEAL BROKEN BY
DATE
EPA FORM
7500-2 (R7-75)

CH2M HILL
SAMPLE IDENTIFICATION MATRIX

BY: _____ DATE: _____ PROJECT NO: _____

SITE _____

ACTIVITY _____

CASE/SAS NUMBER _____

INSTRUCTIONS

- ONE SI MATRIX PER COOLER/CCC
- SEND SI MATRIX WITH SAMPLE CODE OBSCURED TO LAB
- SEND SI MATRIX TO SMO
- ANALYSIS CODES COMPLETED BY SAMPLERS IN ACCORDANCE WITH CLP REQUEST
- ONE CONTAINER AND TAG NUMBER PER LINE

NOTES _____

STATION LOCATION	SAMPLE TYPE	SAMPLE CODE	ANALYSIS CODE	SMO NUMBER	SAMPLE TAG NUMBER	BOTTLE SIZE & TYPE	QC BOTTLE LOT NUMBER	DATE/TIME SAMPLED 19__	PRESERVATION CODE	COMMENTS

CLP LABORATORY _____ PHONE _____

CHAIN OF CUSTODY NUMBER _____

DATE SHIPPED/CARRIER _____

AIRBILL NUMBER _____

ANALYSIS CODES _____

SAMPLE TYPES: GW = GROUND WATER
SW = SURFACE WATER
SE = SEDIMENT
SC = SOIL CORE
-G = GRAB SAMPLE
-C = COMPOSITE
-F = FILTERED
-U = UNFILTERED
EXAMPLE: SW-G-F = FILTERED SURFACE WATER GRAB SAMPLE

SMO NUMBER: ITR NUMBER
OTR NUMBER
SAS PACKING LIST NUMBER
MATR NUMBER

SAMPLE CODES: N = NATURAL SAMPLE
R = REPLICATE
EB = EQUIPMENT BLANK
SPS = SURFACE SPIKE
FS = FIELD SPIKE
SB = SOIL BLANK
WB = WATER BLANK
BB = BOTTLE BLANK

BOTTLE SIZE & TYPE: 4 AGB = 1 LITER AMBER GLASS BOTTLE
8 AGB = 40 OZ. AMBER GLASS BOTTLE
40 CV = 40 ML GLASS VIAL
1 LPB = 1 LITER POLYETHYLENE BOTTLE
16 WMG = 16 OZ WIDE MOUTH GLASS JAR
8 WMG = 8 OZ WIDE MOUTH GLASS JAR
32 WMG = 32 OZ WIDE MOUTH GLASS JAR
4 WMG = 4 OZ WIDE MOUTH GLASS JAR

CH2M HILL-DENVER 1-800-525-7564
SAMPLE MANAGEMENT OFFICE
(PAULA ALEXANDER) 783/337-1468
FEDERAL EXPRESS ACCT. NO. 1668-1575-1

PRESERVATIVE CODE: NP = UNPRESERVED
RNP = REFRIGERATED/ICED AT 4°C OR LOWER
RPT = REFRIGERATED/ICED AT 4°C OR LOWER AND HNO3 (NITRIC ACID) ADDITION TO pH ≤ 2
RPT = REFRIGERATED/ICED AT 4° OR LOWER AND NaOH (SODIUM HYDROXIDE) ADDITION TO pH ≥ 12

FEDERAL EXPRESS

USE THIS AIRBILL FOR DOMESTIC SHIPMENTS WITHIN THE CONTINENTAL U.S.A., ALASKA AND HAWAII.
COMPLETE PURPLE AREAS. FOR ASSISTANCE, CALL 800-238-5355 TOLL FREE.
SEE BACK OF FORM SET FOR COMPLETE PREPARATION INSTRUCTIONS.

SENDER'S FEDERAL EXPRESS ACCOUNT NUMBER: 60588 1000-5628-1

DATE: 5/12/87

1 From (Your Name): WILLIAM SCHAFFER — Your Phone Number (Very Important): (406) 587 3477

Company: ~~H & H HILL~~ SCHAFER & ASSOC — Department/Floor No.:

Street Address: ~~5993 S SYRACUSE~~ 6111 N WILLOW #1B

City: ~~ENGLEWOOD~~ BOZEMAN, MT — State: ~~CO~~

ZIP ® Zip Code Required For Correct Invoicing: ~~80111~~

AIRBILL NO. 856088170

2 To (Recipient's Name): ACCU LABS RESEARCH — Recipient's Phone Number (Very Important): (303)

Company: ATT: DANA HAEN — Department/Floor No.:

Exact Street Address (Use of P.O. Boxes or P.O. ® Zip Codes Will Delay Delivery And Result In Extra Charge.): 11485 W. 48TH AVE.

City: WHEATRIDGE, CO — State:

ZIP Street Address Zip Required (Use P.O. Box ® Zip Code): 80033

3 YOUR BILLING REFERENCE INFORMATION (FIRST 24 CHARACTERS WILL APPEAR ON INVOICE.)

PAYMENT: ☐ Bill Shipper ☐ Bill Recipient's FedEx Acct. No. Fill in line below ☒ Bill 3rd Party FedEx Acct. No. Fill in line below ☐ Bill Credit Card Fill in line below ☐ Cash

FedEx Acct. No. or Major Credit Card No.: 1000-5621-1

4 SERVICES — CHECK ONLY ONE BOX

☒ PRIORITY 1 Overnight Delivery (Using Your Packaging) 6 ☐ OVERNIGHT LETTER (Our Packaging) 9" x 12"

OVERNIGHT DELIVERY USING OUR PACKAGING

2 ☐ Courier-Pak Overnight Envelope 12" x 15½"

☐ Overnight Box 12½" x 17½" x 3" A ☐

☐ Overnight Tube 38" x 6" x 6" B ☐

STANDARD AIR ☐ Delivery not later than second business day

SERVICE COMMITMENT

PRIORITY 1 - Delivery is scheduled early next business morning in most locations. It may take two or more business days if the destination is outside our primary service areas.

STANDARD AIR - Delivery is generally next business day or not later than second business day. It may take three or more business days if the destination is outside our primary service areas.

DELIVERY AND SPECIAL HANDLING CHECK SERVICES REQUIRED

1 ☐ HOLD FOR PICK-UP Give the Federal Express address where you want package held in Section H at right.

2 ☒ DELIVER WEEKDAY

3 ☐ DELIVER SATURDAY (Extra charge applies)

4 ☐ RESTRICTED ARTICLES SERVICE (P-1 and Standard Air Packages only. Extra charge applies.)

5 ☐ CONSTANT SURVEILLANCE SERVICE (CSS) (Extra charge applies.)

6 ☐ DRY ICE _____ Lbs.

7 ☐ OTHER SPECIAL SERVICE _____

8 ☐

9 ☐ SATURDAY PICK-UP OR SATURDAY DROP-OFF (Extra charge applies.)

	PACKAGES	WEIGHT	YOUR DECLARED VALUE (See right)	OVER SIZE
	1			
Total	1	Total	Total	

Received At: Shipper's Door ☐ Regular Stop ☐ On-Call Stop ☐ FedEx Loc. _____

Federal Express Courier Employee No.: 41457

Date/Time For Federal Express Use: 5/12 1809

H HOLD FOR PICK-UP AT THIS FEDERAL EXPRESS STATION:
Street Address (See Service Guide or Call 800-238-5355)

City: State:

ZIP ® Zip Code of Street Address Required

YOUR DECLARED VALUE

DAMAGE OR LOSS

We are liable for no more than $100 per package in the event of physical loss or damage, unless you fill in a higher Declared Value to the left and document higher actual loss in the event of a claim. We charge 30¢ for each additional $100 of declared value up to the maximum shown in our Service Guide. Declared value restrictions are shown on the back of the Shipper's Copy of this airbill. We make no express or implied warranties.

DELAY

There is always a risk of late delivery or non-delivery. In the event of a late delivery Federal Express will, at your request, refund all transportation charges paid. See back of Shipper's Copy of this airbill for further information.

CONSEQUENTIAL DAMAGES

We will not be responsible or liable for any loss or damage resulting from delay, non-delivery or damage to a package, except as noted above. This includes loss of sales, income, interest, profits, attorneys fees and other costs, but is not limited to these items. Such damages are called "consequential damages."

Federal Express Use

Base Charges

Declared Value Charge

Origin Agent Charge

Other

Total Charges

SHIPPER'S COPY/RETAIN FOR TRACE PURPOSES.

PART #2041738901
FEC-S-751-1000
REVISION DATE 10 85
PRINTED U S A NCR

APPENDIX C
DESCRIPTION OF SPECIAL EQUIPMENT

TEMPE CELLS
CARWA APPARATUS
GUELPH PERMEAMETER

OPERATING INSTRUCTIONS for the

Cat. No. 1400

TEMPE PRESSURE CELL

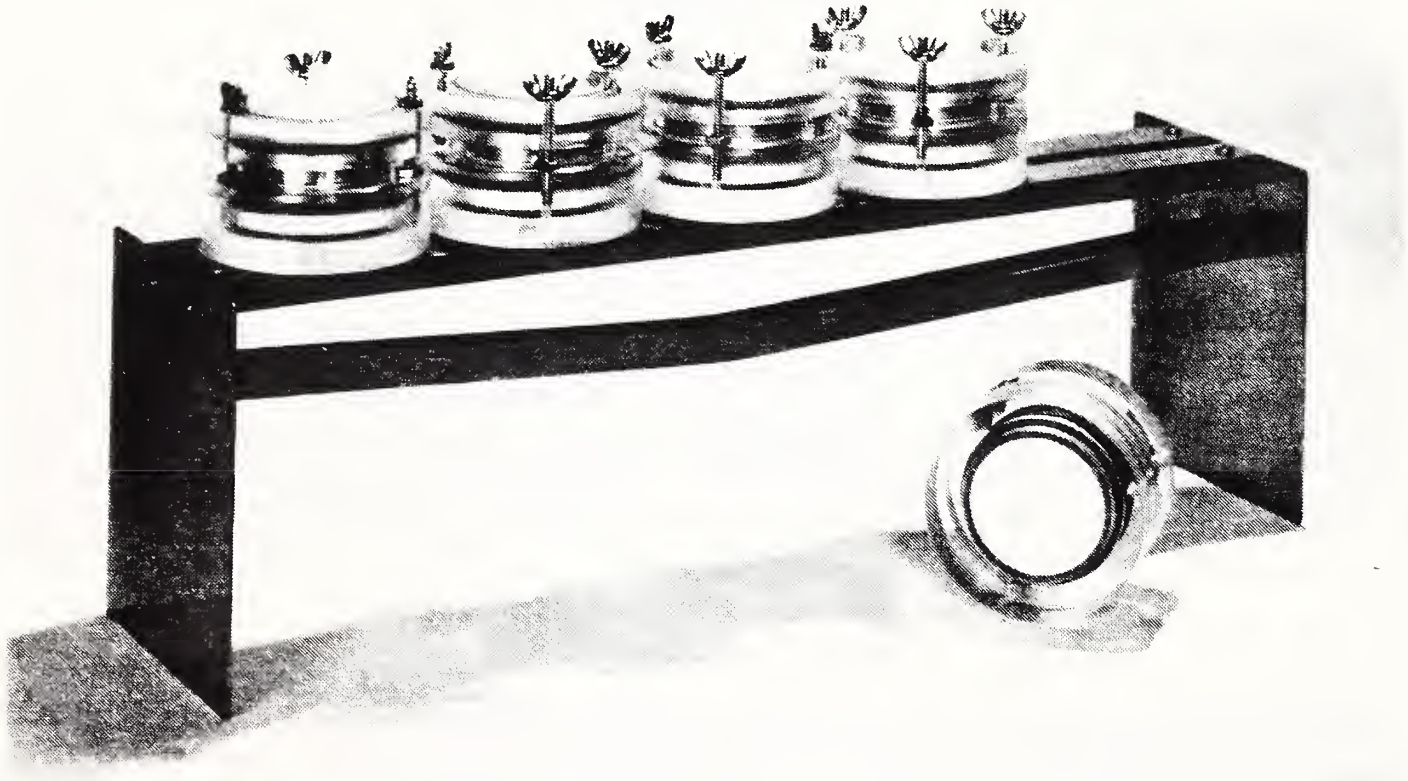


FIG. 1 TEMPE PRESSURE CELLS SHOWN MOUNTED ON CAT. NO. 1425 TEMPE CELL STAND.

FIG. 2 DISASSEMBLED TEMPE PRESSURE CELL SHOWING WORKING PARTS.

FIG. 3 CAT. NO. 200 SOIL CORE SAMPLER USED TO OBTAIN UNDISTURBED SOIL CORES.

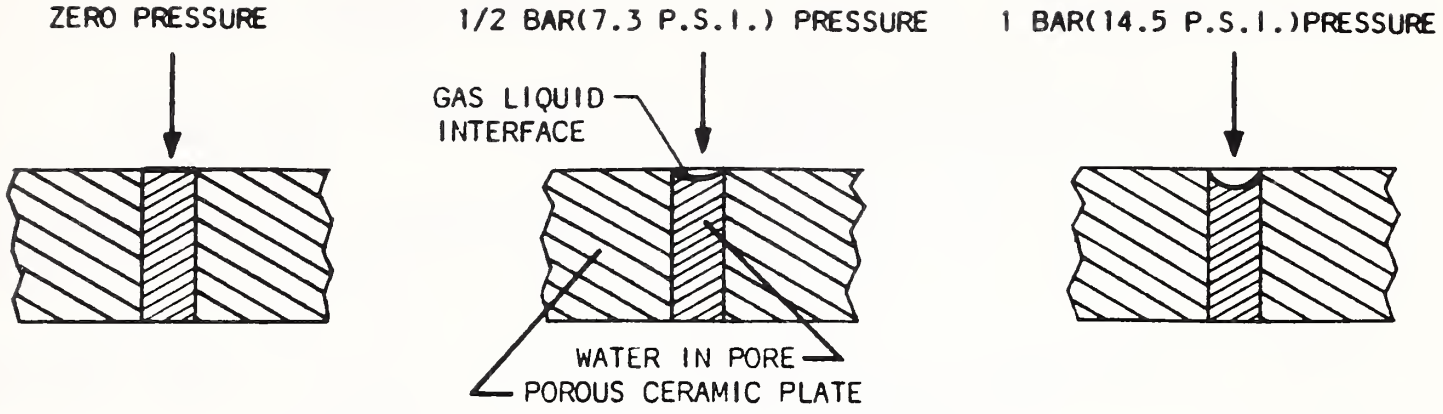


FIG. 5 CHANGES IN RADIUS OF CURVATURE OF GAS-LIQUID INTERFACE WITH PRESSURE

DURING A RUN, AT ANY SET AIR PRESSURE IN THE EXTRACTOR, SOIL MOISTURE WILL FLOW FROM AROUND EACH OF THE SOIL PARTICLES AND OUT THROUGH THE CERAMIC PLATE UNTIL SUCH TIME AS THE EFFECTIVE CURVATURE OF THE WATER FILMS THROUGHOUT THE SOIL ARE THE SAME AS AT THE PORES IN THE PLATE. WHEN THIS OCCURS, AN EQUILIBRIUM IS REACHED AND THE FLOW OF MOISTURE CEASES. WHEN THE AIR PRESSURE IN THE EXTRACTOR IS INCREASED, FLOW OF SOIL MOISTURE FROM THE SAMPLES STARTS AGAIN AND CONTINUES UNTIL A NEW EQUILIBRIUM IS REACHED. AT EQUILIBRIUM, THERE IS AN EXACT RELATIONSHIP BETWEEN THE AIR PRESSURE IN THE EXTRACTOR AND THE SOIL SUCTION (AND HENCE THE MOISTURE CONTENT) IN THE SAMPLES. FOR EXAMPLE, IF THE AIR PRESSURE IN THE EXTRACTOR IS MAINTAINED AT 1/3 BAR (4.8 PSI), THE SOIL SUCTION IN THE SAMPLES AT EQUILIBRIUM WILL BE 1/3 BAR.*

APPLICATION AND FEATURES

THE CAT. NO. 1400 TEMPE PRESSURE CELL PROVIDES NEW SIMPLICITY IN THE DETERMINATION OF SOIL MOISTURE-RETENTION CURVES, OR THE "MOISTURE CHARACTERISTIC", OF UNDISTURBED SOIL CORES IN THE 0-1 BAR RANGE. THIS MOISTURE CHARACTERISTIC OF FIELD SOILS IS READILY AND VERY ACCURATELY DETERMINED BY WEIGHING THE COMPLETE CELL AT PRESSURE EQUILIBRIUM POINTS. FIG. 1, PG. 1, SHOWS THE ASSEMBLED TEMPE PRESSURE CELLS AS NORMALLY MOUNTED ON THE CAT. NO. 1425 TEMPE CELL STAND. FIG. 2, PG. 1, SHOWS THE VARIOUS PARTS OF THE DISASSEMBLED CELL.

THE CELL ACCEPTS THE UNDISTURBED SOIL CORE CONTAINED IN THE BRASS CYLINDER DIRECTLY FROM THE CAT. NO. 200 SOIL CORE SAMPLER. FIG. 3, PG. 1, SHOWS THE VARIOUS PARTS OF THE CAT. NO. 200 SOIL CORE SAMPLER AS IT IS NORMALLY SUPPLIED. BY THIS MEANS THE SAMPLE IS NOT DISTURBED BY UNNECESSARY HANDLING AND THE RESULTANT CURVE WILL ACCURATELY REFLECT THE TRUE CHARACTERISTICS OF THE SOIL IN THE VERY IMPORTANT 0-1 BAR RANGE OF SOIL SUCTION WHERE ALMOST ALL OF THE SOIL MOISTURE MOVEMENT TAKES PLACE.

THE BODY PARTS OF THE CELL ARE CONSTRUCTED OF PLEXIGLASS, PERMITTING UNRESTRICTED VIEW OF THE INTERNAL PARTS AND ACTIVITY. THE PRESSURE SEALS ARE MADE BY RUBBER "O" RINGS. FIG. 4, PG. 2, INDICATES THE CATALOG NUMBER OF THE VARIOUS PARTS OF THE CELL THAT MAY BE NEEDED FOR REPLACEMENT PURPOSES.

*NOTE: THE "BAR" HAS BECOME A STANDARD UNIT FOR THE EXPRESSION OF SOIL SUCTION. BY DEFINITION, A BAR IS A UNIT OF PRESSURE EQUAL TO 10 DYNE/CM. THIS IS EQUIVALENT TO .987 ATMOSPHERES OR 14.5 PSI.

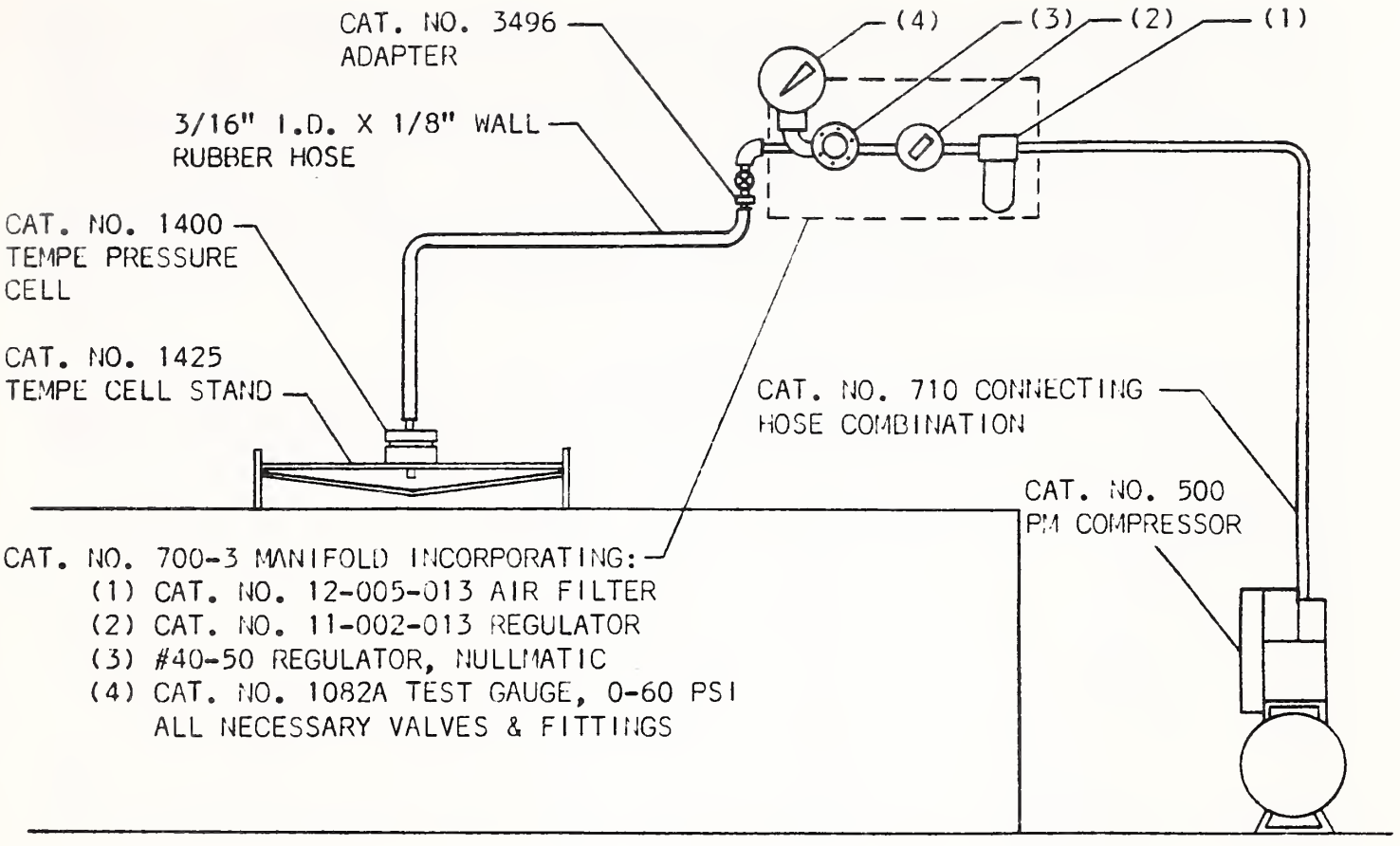


FIG. 6 LABORATORY SETUP FOR CAT. NO. 1400 TEMPE PRESSURE CELL WITH THE CAT. NO. 500 PM COMPRESSOR AS PRESSURE SOURCE

GAS SINCE IT "BLEEDS" A SMALL AMOUNT OF AIR CONTINUOUSLY FROM THE AIR SOURCE IN THE PROCESS OF REGULATION. THIS AMOUNT OF AIR IS READILY REPLACED BY A COMPRESSOR BUT IT WOULD DRAIN A TANK OF COMPRESSED GAS IN A MATTER OF HOURS.

THE CAT. NO. 1400 TEMPE PRESSURE CELL CAN ALSO BE OPERATED FROM COMPRESSED AIR OR NITROGEN IN TANKS. OUR CAT. NO. 750-3 MANIFOLD IS DESIGNED FOR USE WITH WATER PUMPED NITROGEN IN TANKS (APPROX. 2000 PSI). THIS MANIFOLD HAS A PRESSURE RANGE FROM 0-125 PSI WITH AN ACCURACY OF REGULATION OF APPROXIMATELY .2 PSI.

THE 750-3 MANIFOLD MAY ALSO BE INCORPORATED IN COMBINATION MANIFOLDS SUCH AS THE CAT. NO. 750-13, 750-23, 750-123, WHERE SEVERAL DIFFERENT TYPES OF EXTRACTORS ARE BEING RUN INDEPENDENTLY FROM THE SAME PRESSURE SOURCE. THE 750 SERIES MANIFOLD ALL INCORPORATE A CAT. NO. 510B15 REGULATOR WHICH IS DESIGNED TO MOUNT DIRECTLY ON TANKS OF WATER PUMPED NITROGEN WITH A TANK FITTING DESIGNATED AS CGA NO. 580, WHICH IS STANDARD.

IF A PRESSURE CONTROL SETUP IS TO BE BUILT UP BY THE LABORATORY TECHNICIANS, CARE SHOULD BE EXERCISED IN THE SELECTION OF PROPER COMPONENTS. PROPER PRESSURE REGULATORS, TEST GAUGES, VALVES AND MISCELLANEOUS ADAPTERS ARE AVAILABLE AT SOILMOISTURE EQUIPMENT CORP. AND THE CURRENT PRICE LIST SHOULD BE CONSULTED. IN GENERAL, THE TYPE OF PRESSURE REGULATOR REQUIRED WILL DEPEND ON THE TYPE OF PRESSURE SOURCE AND ON THE ACCURACY REQUIRED FOR THE STUDIES BEING CONDUCTED. ACCURACY OF REGULATION IS DEPENDENT ON THE CONSTRUCTION OF THE REGULATOR AND ALSO ON VARIATIONS IN THE PRESSURE FROM THE SOURCE OF SUPPLY.

WITH REGULATORS SUITABLE FOR USE WITH THIS EXTRACTOR, ONE CAN EXPECT VARIATION

NOTING THE DIFFERENCE IN WEIGHT, YOU KNOW THE CHANGE IN WEIGHT FROM ONE SOIL SUCTION VALUE TO ANOTHER. AT THE END OF A RUN THE SAMPLE CAN BE DRIED AT 105°C. AND THEN THE CHANGES IN WEIGHT CAN BE INTERPRETED IN TERMS OF MOISTURE CONTENT BY WEIGHT OF SOIL. SINCE THE VOLUME OF THE SOIL SAMPLE IS WELL DEFINED BY THE DIMENSIONS OF THE BRASS RETAINING RING, THE MOISTURE CONTENT CAN ALSO BE RELATED TO THE VOLUME OF SOIL. BY PLOTTING THE CHANGE IN MOISTURE CONTENT AT EACH EQUILIBRIUM VALUE AGAINST THE SOIL SUCTION IN BARS FOR THAT EQUILIBRIUM VALUE YOU DEVELOP THE FUNDAMENTAL RELATIONSHIP OF SOIL SUCTION VERSUS MOISTURE CONTENT FOR EACH SOIL. THE GRAPH OBTAINED IS CALLED THE "MOISTURE CHARACTERISTIC" FOR THE SOIL.

SHOWN BELOW ARE TYPICAL CURVES AS DEVELOPED BY R. J. REGINATO AND C.H.M. VAN BAVEL IN THEIR ORIGINAL WORK ON THE TEMPE PRESSURE CELLS AT THE WATER CONSERVATION LABORATORY AT TEMPE, ARIZONA, U.S.

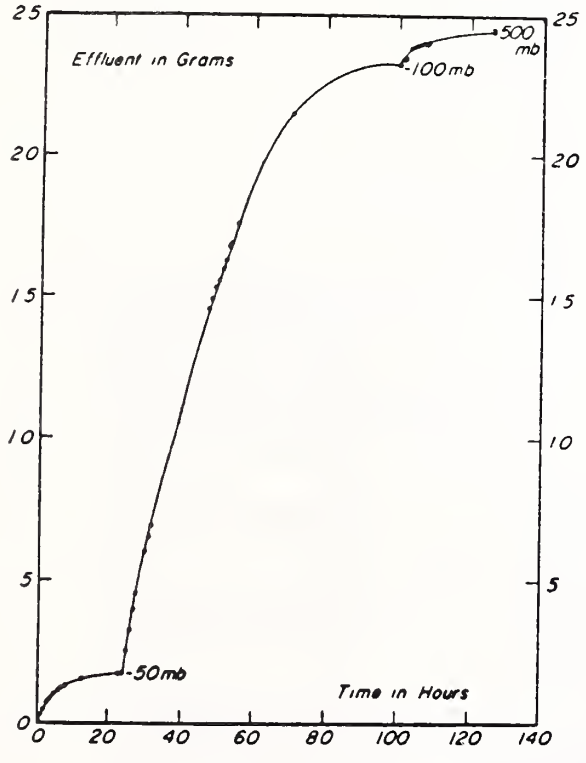


FIG. 7 AMOUNT OF WATER RELEASED AT THREE PRESSURE POTENTIALS VS. TIME FOR 50-500 SAND USING CERAMIC PLATE IN CELL.

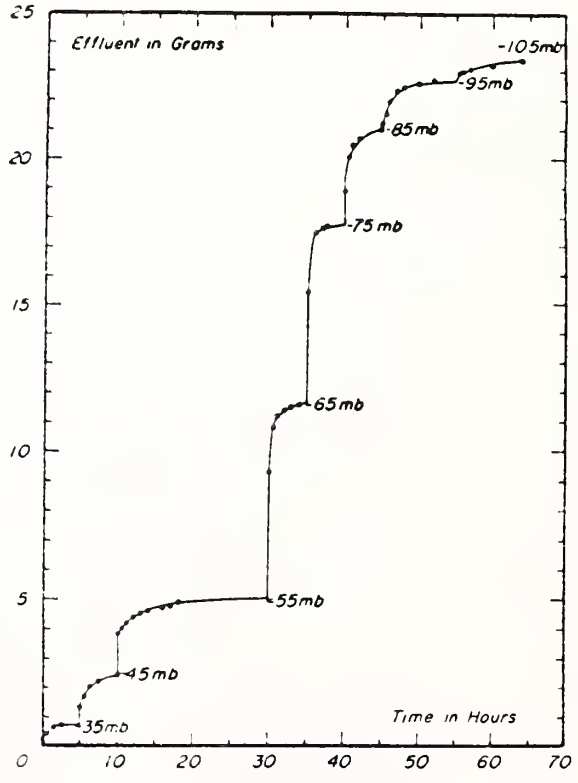


FIG. 8 AMOUNT OF WATER RELEASED AT EIGHT PRESSURE POTENTIALS VS. TIME FOR 50-500 SAND USING HIGH CONDUCTANCE POROUS METAL PLATE IN CELL.

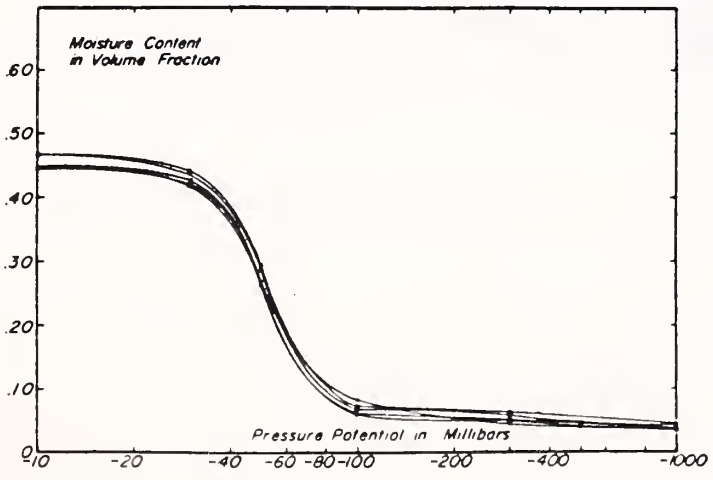


FIG. 9 MOISTURE CHARACTERISTIC OF 50-500 SAND. FIVE REPLICATES ARE SHOWN

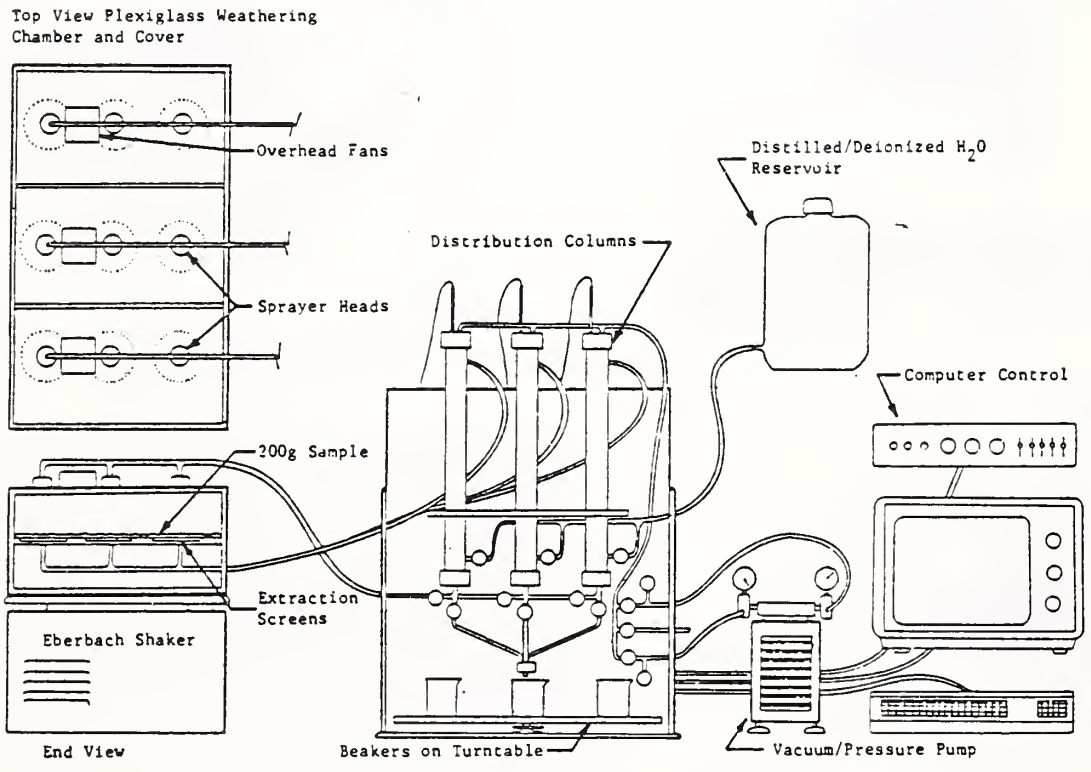


Figure . Diagram of the computerized automated rapid weathering apparatus prototype.

NOTICE

MODEL 2800 GUELPH PERMEAMETER

As of January 1987, Model 2800K1 Guelph Permeameter comes equipped with an improved airtight seal as part of Part No. 2800-011, Reservoir Cap. As shown in the Engineering Sketch below, the Reservoir Cap now includes a removable "O" Ring Seal (Fig. 1).

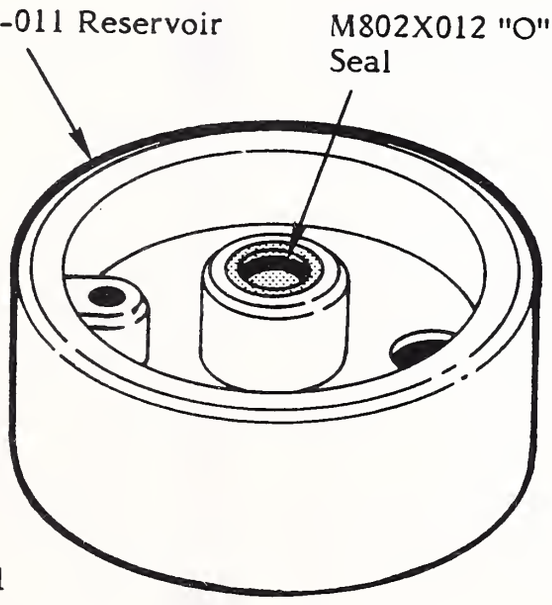


Fig. 1

Should it become necessary to replace the "O" Ring Seal, a wooden toothpick or similar implement should be used to remove the old "O" Ring and replace the new (Fig. 2). Sharp, pointed metal implements are not recommended for use when removing the "O" Ring because damage may be caused to the "O" Ring.

Fig. 2

A thin film of vacuum grease should be applied to the "O" Ring to insure the airtight seal (Fig. 3).

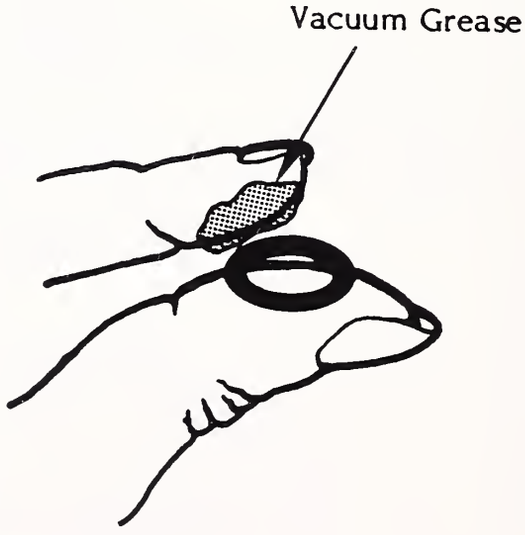


Fig. 3

SOILMOISTURE EQUIPMENT CORP.
P.O. Box 30025
Santa Barbara, CA 93105
U.S.A.

Telphone No. 805-964-3525
Telex No. 65-8424 Fax No. 805-683-2189
Cable Address: SOILCORP

SOILMOISTURE

2800KI OPERATING INSTRUCTIONS

GUELPH PERMEAMETER REV 8/86

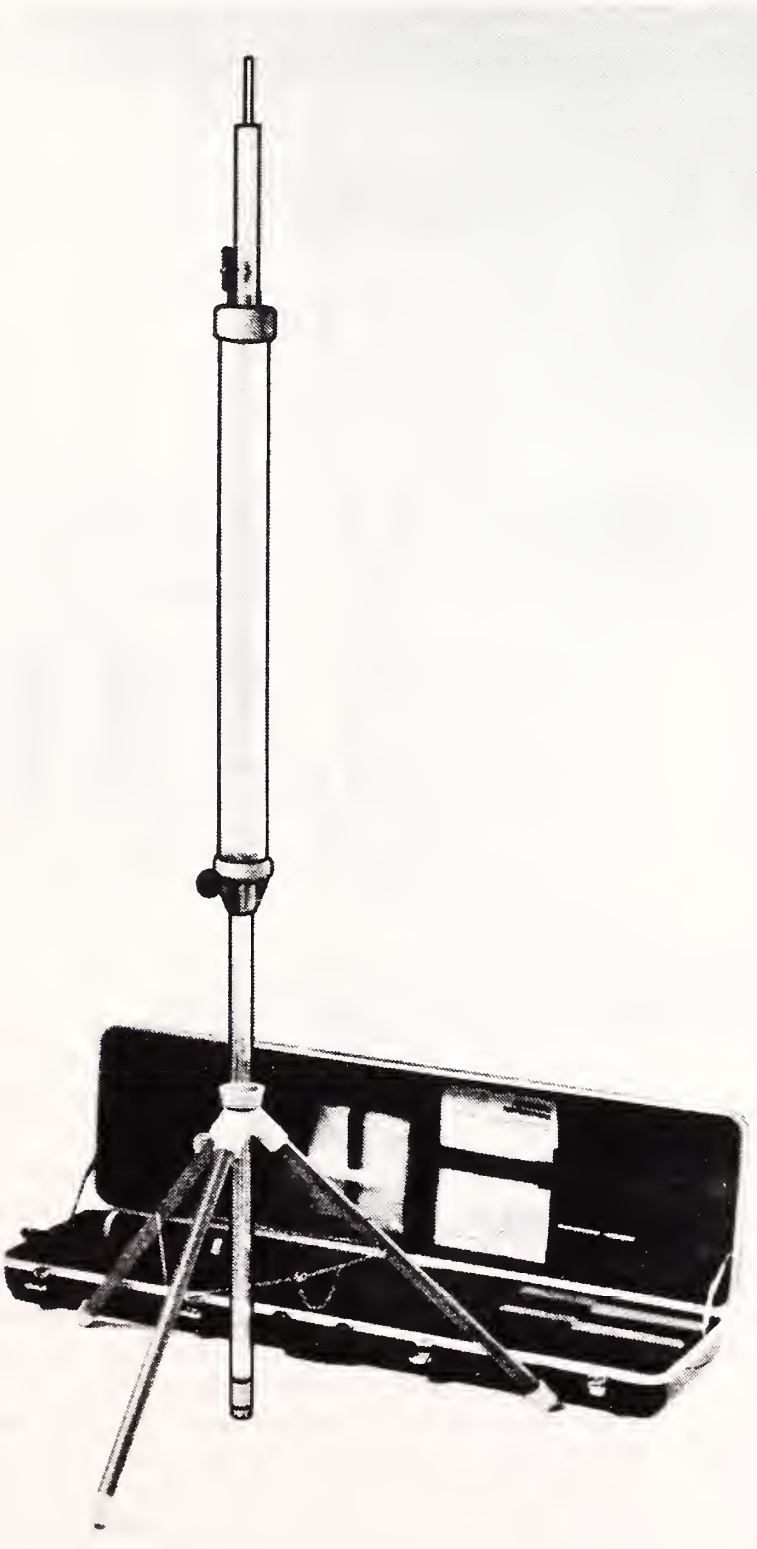


Fig. 1

TABLE OF CONTENTS

Unpacking	Page 1
Acquaint Yourself with the Parts	Page 2-5
Tripod Assembly	Page 2
Support Tube and Fittings	Page 2
Reservoir Assembly	Page 3
Reservoir Base	Page 4
Reservoir Cap	Page 4
Well Head Scale and Fittings	Page 4
Auxiliary Tools	Page 5
Specifications of Unit	Page 5
Requirements Prior to First Use	Page 5
Procedures for Field Use	Page 6-11
Flow Chart	Page 6
Well Preparation	Page 7
Permeameter Assembly	Page 9
Water Filling	Page 11
Placement of Permeameter	Page 11
Making a Reading	Page 12-13
Standardized Calculations	Page 14
Hydraulic Conductivity & Matric Flux Potential	Page 14
Sorptivity	Page 14
Alph Parameter	Page 14
Measurement Example	Page 15-16
Making a Reading in Deep Wells	Page 17
Making a Reading with Limited Water Supply	Page 17
Use and Applications	Page 18
Helpful Hints in Normal Use	Page 19
General Care and Maintenance	Page 19-20
Trouble Shooting	Page 21
Theory	Page 22
Generalized Calculations	Page 23
Bibliography and Glossary	Page 24
Graph "C" Factor Versus H/a	Page 25
Measurement Forms	Page 26-27
Parts List and Accessory Items	Page 28

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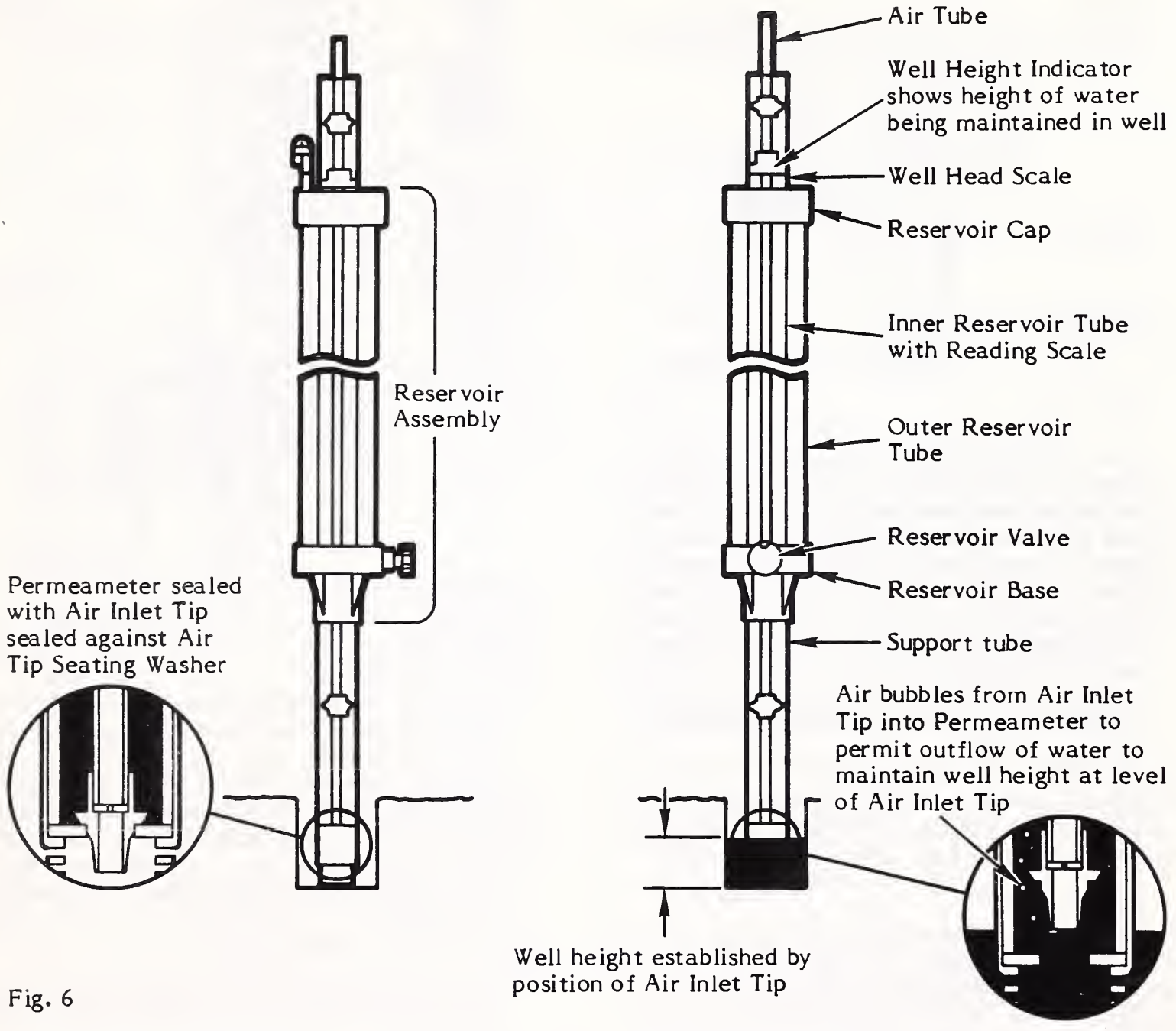

Air Tube
Well Height Indicator shows height of water being maintained in well
Well Head Scale
Reservoir Cap
Inner Reservoir Tube with Reading Scale
Outer Reservoir Tube
Reservoir Valve
Reservoir Base
Support tube
Reservoir Assembly
Permeameter sealed with Air Inlet Tip sealed against Air Tip Seating Washer
Air bubbles from Air Inlet Tip into Permeameter to permit outflow of water to maintain well height at level of Air Inlet Tip
Well height established by position of Air Inlet Tip

Fig. 6

RESERVOIR ASSEMBLY

The reservoir assembly provides a means of storing water and measuring the outflow rate while the Guelph Permeameter is in use. For studies in very low permeability soils, for example clays, use of the inner reservoir alone is required to provide adequate resolution of outflow rate when making a reading. When working in moderate to high permeability soils, for example sands and structured loams, the reservoir combination is used. A scale, delineated in centimeters, is stamped on the Inner Reservoir Tube for measuring the rate of fall of water out of the reservoir in both situations. Fittings are located at the top and bottom of the reservoirs to allow filling and selection of the proper reservoir.

In Fig. 6, above, the reservoir combination is being used to make a reading. The Guelph Permeameter, on the left, shows the closed or sealed state with Air Inlet Tip sealed against Air Tip Seating Washer. As illustrated on the right, upon uplift of the Air Tube with accompanying Air Inlet Tip and Well Height Indicator, water flows from the reservoir down the inside of the Support Tube through the Water Outlet Tip and into the well. The water height in the well is established by the height of the Air Inlet Tip. This water height in the well can be set and read using the Well Height Indicator in conjunction with the Well Head Scale.

RESERVOIR BASE

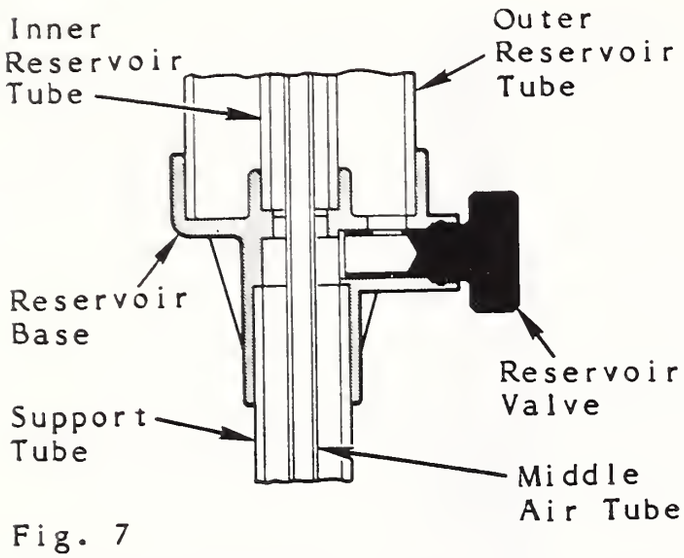


Fig. 7

The Reservoir Base includes the Reservoir Valve. The Reservoir Base connects and seals the Inner and Outer Reservoir Tubes to the Support Tube, see Fig. 7. In use, water flow is controlled by the notched Reservoir Valve. When the notch is pointing straight up, or in the 12 o'clock position, both reservoirs supply water to the well hole. When the notch is pointing straight down, or in the 6 o'clock position, only the Inner Reservoir supplies water to the well hole, see Fig. 8.

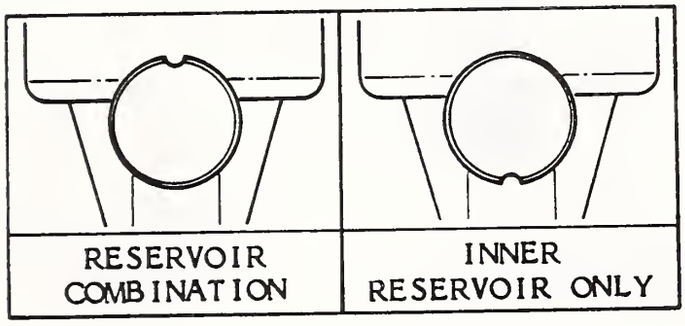


Fig. 8

RESERVOIR CAP

The Reservoir Cap includes the Fill Plug and Vacuum Tube connections. The Reservoir Cap provides an airtight cover for the top of the reservoir, the seal for the Air Tube, and supports the Well Head Scale on the central "boss", see Fig. 9.

The Middle Air Tube is located inside the Inner Reservoir Tube and slides through the sliding airtight seal in the Reservoir Cap. The Well Height Indicator slides over the Middle Air Tube above the Reservoir Cap and indicates on the Well Head Scale the head of water being maintained in the well hole.

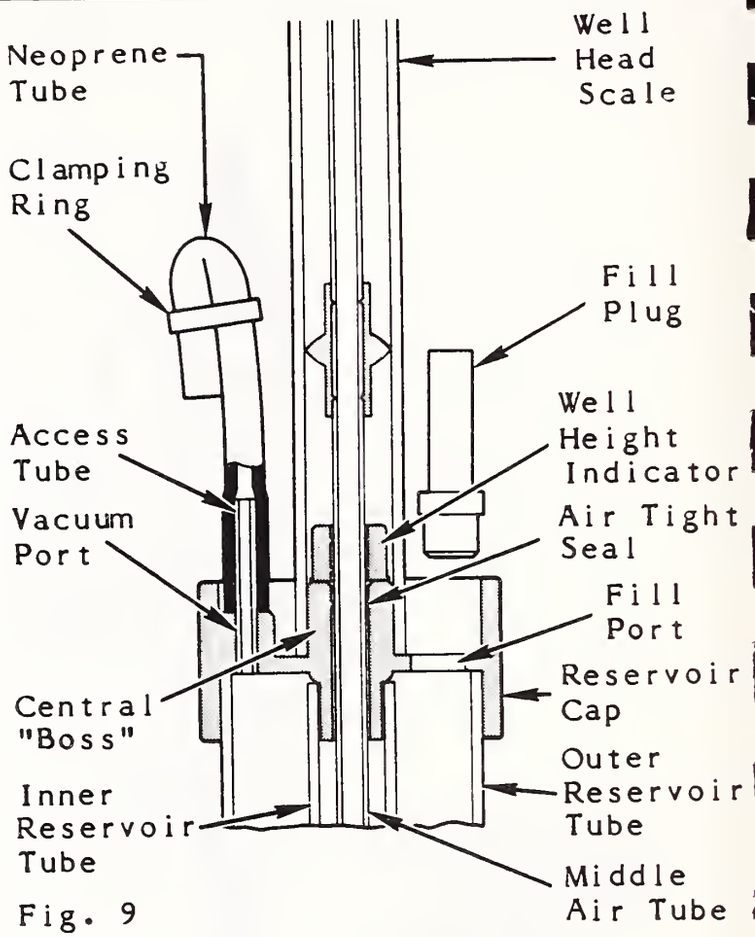


Fig. 9

Two ports are located in the Reservoir Cap. The Reservoirs are filled through the Fill Port and sealed with the Fill Plug. The Vacuum Port consists of an Access Tube, Neoprene Tube and Clamping Ring. The Vacuum Port facilitates pulling a vacuum when the Reservoirs are not initially completely filled. After the vacuum is created, the Neoprene Tube is bent over and closed off with the Clamping Ring.

WELL HEAD SCALE AND UPPER AIR TUBE FITTINGS

The Upper Air tube is connected to the Middle Air Tube with an Air Tube Coupling. The Upper Air Tube serves as an extension to facilitate setting the well head after the Well Head Scale is put in place.

The Well Head Scale is numbered in centimeters and graduated in millimeters. The Well Head Scale is counter bored and fits snugly over the central "boss" on the Reservoir Cap, see Fig. 9.

Once the Air Inlet Tip at the bottom of the permeameter is seated and sealed, the Well Height Indicator is pushed down the Air Tube until it rests against the "boss" on the Reser-

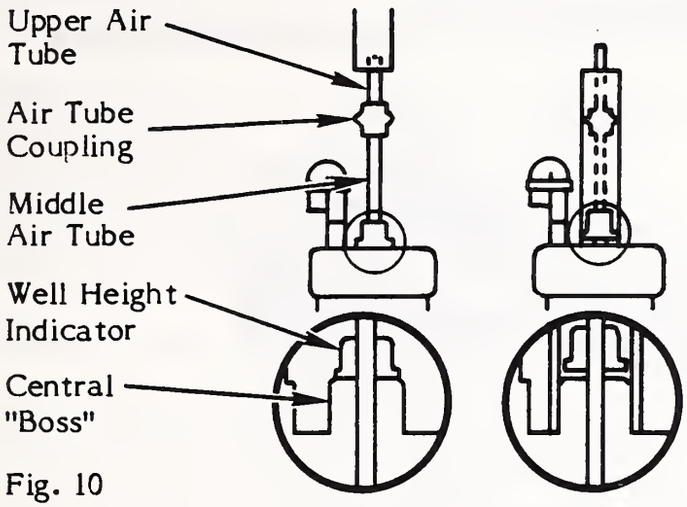


Fig. 10

voir Cap, as shown in Fig. 10. Next the Well Head Scale is mounted. The Air Tube is then pulled up, raising the Well Height Indicator to the height desired. The height is read on the Well Head Scale.

AUXILIARY TOOLS

The Guelph Permeameter Kit includes a Soil Auger for excavating a well, a Sizing Auger, a Well Prep Brush, a Vacuum Hand Pump for pulling a vacuum in the reservoir, and a collapsible Water Container for carrying water to the field, see Fig. 1.

The Well Prep Brush is included to provide a means of removing any smear layer that exists in the augered well hole that may create a barrier to the natural flow of water out of the well into surrounding soil.

The Soil Auger, Sizing Auger, and Well Prep Brush are all equipped with quick connect fitting for use on the same auger shaft.

SPECIFICATIONS OF UNIT

Auger Cutting Diameter
- 6.0 cm (2-3/8")

Well Height Range
- 2.5 cm to 25 cm

Hydraulic Conductivity Range
- 10^{-4} to 10^{-8} m/sec
  (10^{-2} to 10^{-6} cm/sec)

Collapsible Water Container Capacity
- 3.79 liters (1 gallon)

Maximum Permeameter Capacity
- 3.18 liters (.84 gallons)

Overall Carrying Case Size
- 118 cm (46-1/2") long X
  37 cm (14-1/2") wide X
  15 cm (5-3/4") deep

Overall Carrying Case Weight
- 14 kg (30 lbs)

Depth Range, Standard Unit *
- 15-75 cm

* Note: with Extension Tubes, measuring depths can be increased.

NOT LIABLE FOR IMPROPER USE

Soilmoisture Equipment Corp. is not responsible for any damage actual or inferred for misuse or improper handling of this equipment. The Guelph Permeameter is designed to be used soley as directed, by a prudent individual under normal conditions in the applications intended for this instrument.

REQUIREMENTS PRIOR TO FIRST USE

The Guelph Permeameter comes as a complete field-ready kit, with all the equipment necessary to determine field saturated hydraulic conductivity, matric flux potential, and soil sorptivity.

It is highly recommended that users read this instruction manual thoroughly and familiarize themselves with the Standardized Procedure and Standardized Calculations as well as the assembly of the permeameter before beginning formal field investigations. Although very little water is required for each measurement, it is necessary to make provisions for obtaining or bringing water on site.

FLOWCHART OF PROCEDURE FOR STANDARDIZED METHOD OF MEASUREMENT USING THE GUELPH PERMEAMETER

SITE EVALUATION

SOIL TYPE? SUBSURFACE? ANOMALIES?

↓

WELL HOLE PREPARATION

↓

ASSEMBLE PERMEAMETER

↓

FILL RESERVOIRS

↓

PLACE PERMEAMETER

↓

SELECT RESERVOIR

RESERVOIR COMBINATION (FAST BUBBLING)	INNER RESERVOIR (SLOW BUBBLING)
SET H_1 = 5 cm — DETERMINE $\overline{R}_1$	SET H_1 = 5 cm — DETERMINE $\overline{R}_1$
↓	↓
SET H_2 = 10 cm — DETERMINE $\overline{R}_2$	SET H_2 = 10 cm — DETERMINE $\overline{R}_2$
↓	↓
CALCULATE $K_{fs} = (.0041)(X)(\overline{R}_2) - (.0054)(X)(\overline{R}_1)$ $\phi_m = (.0572)(X)(\overline{R}_1) - (.0237)(X)(\overline{R}_2)$	CALCULATE $K_{fs} = (.0041)(Y)(\overline{R}_2) - (.0054)(Y)(\overline{R}_1)$ $\phi_m = (.0572)(Y)(\overline{R}_1) - (.0237)(Y)(\overline{R}_2)$

In the preceding flowchart, the following terms are used, and defined as follows:

- H_1 = The first head of water established in the well hole, measured in cm.
- $\overline{R}_1$ = The steady state rate of fall of water in the reservoir when the first head H_1 of water is established. Rate of fall expressed in cm/sec.
- H_2 = The second head of water established in the well hole, measured in cm.
- $\overline{R}_2$ = The steady state rate of fall of water in the reservoir when the second head H_2 of water is established. Rate of fall expressed in cm/sec.
- X = Reservoir constant, used when reservoir combination is selected, and corresponds to the cross sectional area of the combined reservoirs expressed in cm^2.
- Y = Reservoir constant used when the inner reservoir only is selected, expressed in cm^2.
- K_{fs} = Field-saturated hydraulic conductivity expressed in cm/sec.
- ϕ_m = Matric flux potential, expressed in cm^2/sec.

The above terms and procedures are explained in detail in the following pages of this instruction booklet.

PROCEDURES FOR FIELD USE

Before making a measurement with the Guelph Permeameter in the field, it is necessary to perform a site and soil evaluation, prepare a well hole, assemble the permeameter, fill the Reservoirs, and place the permeameter in the well hole.

SITE AND SOIL EVALUATION

Upon arrival at the site, the user must evaluate the site with regard to topography, general soil appearance, and intended application, and select the number and location of areas which will be representative of the soils under study.

WELL PREPARATION

The implements needed for excavating and preparing a well bore-hole are included in the Guelph Permeameter Kit. They consist of a two-piece handle, which is assembled as shown in Fig. 11, and three interchangeable auxiliary tools which are connected to the handle by means of the quick connect fitting, shown in Fig. 11.

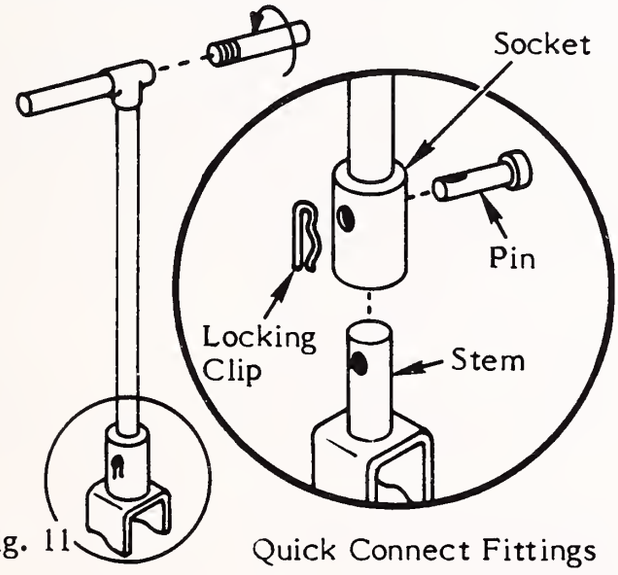


Fig. 11 Quick Connect Fittings

The Soil Auger, shown in Fig. 12, is used to remove bulk amounts of soil and rock. Auger the well hole by rotating the handle in a clockwise direction while applying steady, somewhat firm downward pressure on the handle, as in Fig. 12. When the bucket is full, lift the auger out of the hole and invert it so that the collected sample slips out of the open end of the bucket. When augering, be careful to keep the shaft of the auger handle vertical to avoid excessive enlargement of the well hole.

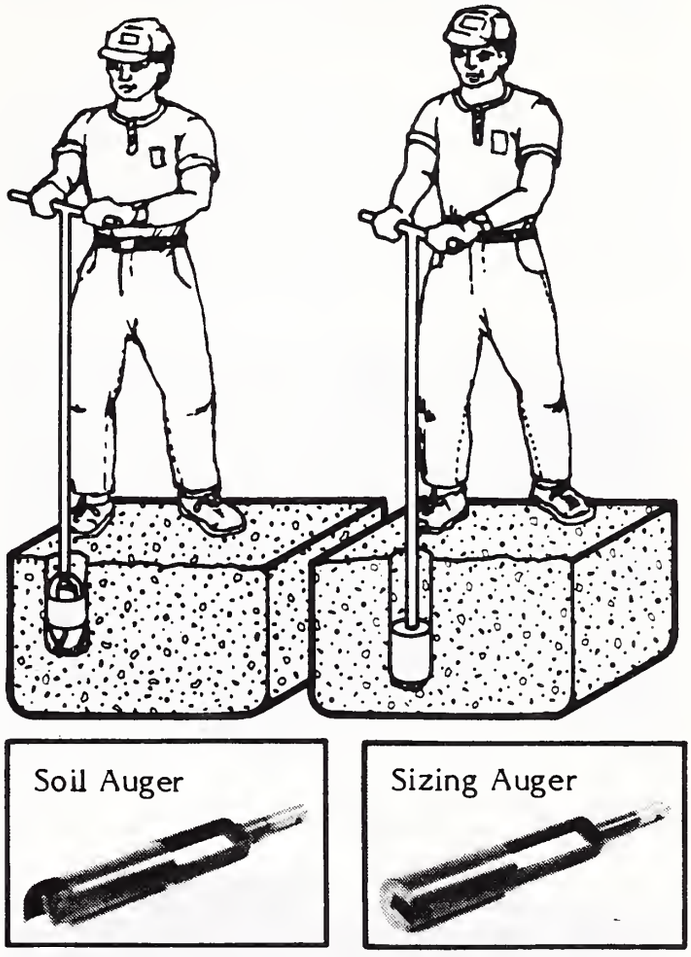


Fig. 12

The Sizing Auger, shown in Fig. 12, is used as a finishing tool to produce a proper sized well hole of uniform geometry and to clean debris off the bottom of the well hole. The Sizing Auger is designed to produce a hole that is uniformly 6 cm in diameter with a flat bottom.

Generally, the preferred procedure is to use the Soil Auger to excavate the well hole down to a depth 15 cm less than that desired for the final well hole. The last 15 cm can then be excavated using the Sizing Auger to produce a debris-free well hole of uniform geometry.

In rocky or gravelly soils, it may be necessary to use the Soil Auger to excavate all the way to the bottom of the well hole. The Sizing Auger is then used afterwards to clean loose debris off the bottom of the well hole.

In medium textured soils of good tilth that are rock free, the well hole is started with the Soil Auger to a shallow depth and then the Sizing Auger alone can be used to excavate the well hole.

Variations of the above recommended procedures for excavating the well hole can be used as soil conditions dictate.

The soil and site evaluation is an ongoing process and soil textural and structural stratification should be identified while augering the hole. A record of this information is an important part of measuring and reporting the hydraulic properties of soil materials.

In moist soils, or in medium to fine textured soils, the process of augering a hole may create a smear layer which can block the natural flow of water out of the well into the surrounding soil. In order to obtain reliable and representative results using the Guelph Permeameter, this smear layer must be removed. The Well Prep Brush is provided for this purpose. The Well Prep Brush is designed to use in the standard 6 cm diameter well hole, and has an outside diameter that is somewhat greater than the diameter of the well.

Fig. 13

Attach the Well Prep Brush to the auger shaft using the quick-connect fitting as shown in Fig. 13. Push the Well Prep Brush into the well hole and all the way to the bottom. Next, quickly and evenly pull the Well Prep Brush straight up and out of the well hole, see Fig. 14. When the direction of the brush is reversed, the bristles will dig into the sides of the well hole, roughen the surface and scour the smear layer. This operation should not be done more than once or twice, since each operation removes a layer of soil. Repeated operations will enlarge the hole diameter beyond the desireable limits needed to obtain accurate results.

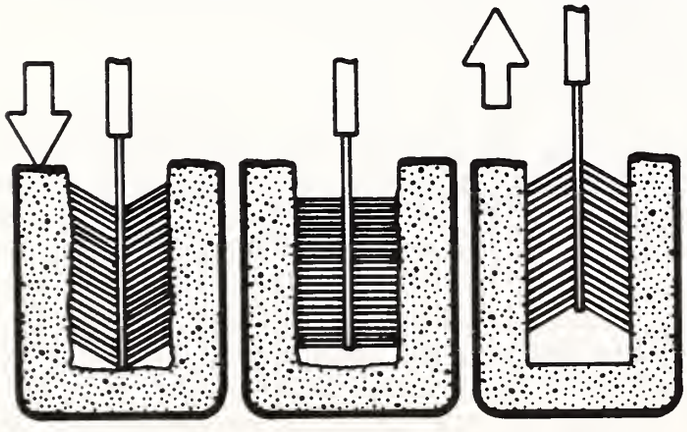


Fig. 14

Typically, the difficulty of removing the smear layer increases with increasing wetness of the soil. It is recommended that fine textured soils not be augered when they are in a very wet state.

PERMEAMETER ASSEMBLY

The Guelph Permeameter Kit is shipped broken down into its component parts to provide convenient storage in its hardshell carrying case and for portability to field sites. The permeameter is easily assembled.

STEP 1

First, assemble the tripod by connecting the Tripod Legs to the Tripod Base. See Fig. 15.

Slip the Tripod Support Chain through the holes in the Tripod Legs and secure the ends of the chain with the "S" Hook as shown in Fig. 16. When working on slopes, flexibility of the Tripod Base allows the angle of the Tripod Legs to be adjusted as needed. In these situations, adjust the Tripod Support Chain length to accommodate leg angle adjustment by moving the "S" hook to the appropriate link on the chain.

Fig. 15

Fig. 16

STEP 2

Next, remove the Reservoir Assembly and the Lower Air Tube from the case. The Lower Air Tube is stored inside the Support Tube, see Fig. 17. Connect the Lower Air Tube to the Middle Air Tube at the base of the Reservoir using the Air Tube Coupling, as shown in Fig. 18. Firmly push the Lower Air Tube into the coupling until the ridge on the inside of the coupling snaps into the groove on the end of the Lower Air Tube.

Fig. 17

Fig. 18

STEP 3

Remove the Tripod Bushing and Support Tube from the case. [illegible] Tripod Bushing, with the wing nut [illegible] into the outside of the Support Tube (see Fig. [illegible]). [illegible] with the Tripod [illegible] Support Tube [illegible] firmly with the recessed [illegible] Reservoir [illegible] Fig. [illegible]. This is an important [illegible] and it is important that the Support Tube be seated completely into the Reservoir Base.

Fig. 19

Fig. [illegible]

STEP 4

The Support Tube can then be lowered into the tripod, as shown in Fig. 21. To support and stabilize the permeameter, push the Tripod Bushing downward fully into the Tripod Base, as shown in Fig. 22.

Fig. 21

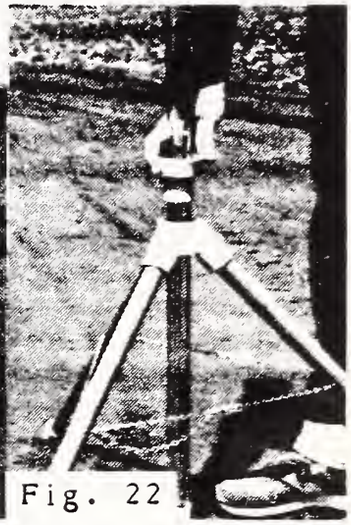


Fig. 22

STEP 5

Remove the Upper Air Tube from its storage inside the Well Head Scale in the carrying case, as shown in Fig. 23.

Before connecting the Upper Air Tube to the Middle Air Tube, make sure that the Well Height Indicator is in place. The Upper Air Tube is connected to the top of the Middle Air Tube with an Air Tube Coupling. Again, when connecting the Air Tube sections, be sure that the ridges on the inside of the coupling fully snap into the grooves on the ends of the Air Tube sections, see Fig. 24.

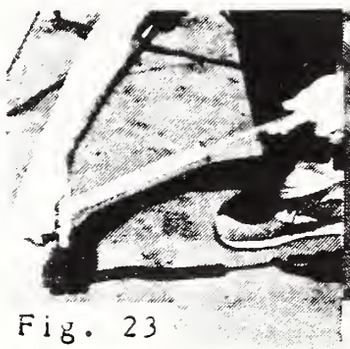


Fig. 23

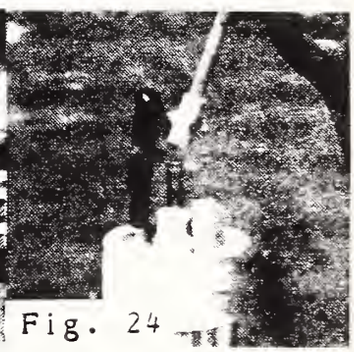


Fig. 24

STEP 6

Fully seat the Air Inlet Tip into the Air Tip Seating Washer by pushing down on the Upper Air Tube, see Fig. 25. Once the Air Inlet Tip is seated, lower and seat the Well Height Indicator flush against the Reservoir Cap, as shown in Fig. 26.

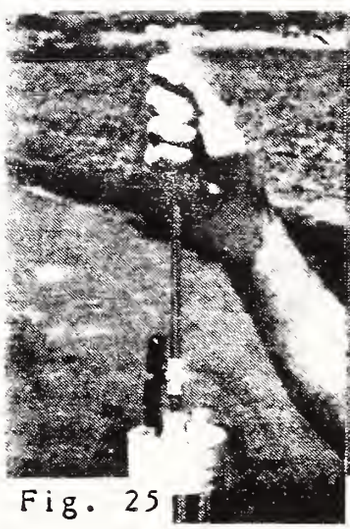


Fig. 25

Fig. 26

STEP 7

Lower the Well Head Scale over the Upper Air Inlet Tube and fully seat it against the bottom of the recess in the Reservoir Cap, see Fig. 27. The counter bore in the Well Head Scale fits snugly onto the central "boss" of the Reservoir Cap. The "MM" mark at the top of the scale should be oriented up. When the Well Head Scale is properly mounted, the "O" reading of the Well Head Scale will be 5 mm below the top of the Reservoir Cap, and the bottom of the Well Height Indicator will line up with the 5 mm mark on the Well Head Scale, see Fig. 28.

Fig. 27

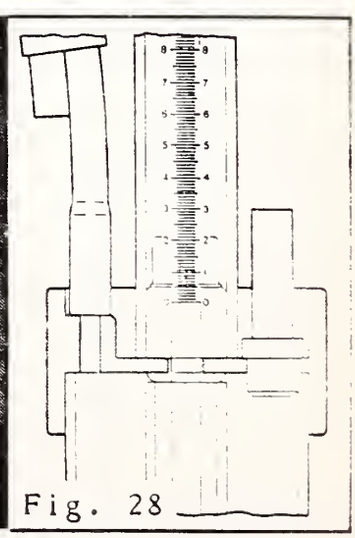


Fig. 28

WATER FILLING

After the permeameter is assembled and mounted in the Tripod, it can be easily filled with water. Remove the Fill Plug in the Reservoir Cap, see Fig. 29 and adjust the Reservoir Valve so that the notch is in the up, or 12 o'clock position see Fig. 30. The Inner and Outer Reservoirs are now connected and ready for filling. Pour the water into the recess on the Reservoir Top Cap. For convenience, the tube assembly can be connected to the plastic water container, and foot pressure used to pump water to the permeameter, as shown in Fig. 31. The recess prevents water from splashing and spilling over. It is important to fill the reservoir until no air bubbles readily emerge from the fill hole. When only limited quantities of water are available and the reservoir cannot be filled completely, follow the procedure on page 17, "Making a Reading With Limited Water Supply". After filling, replace and fully seat the Fill Plug in the fill hole, also make sure that the Neoprene Tube from the Vacuum Port is folded over and closed with the Clamping Ring.

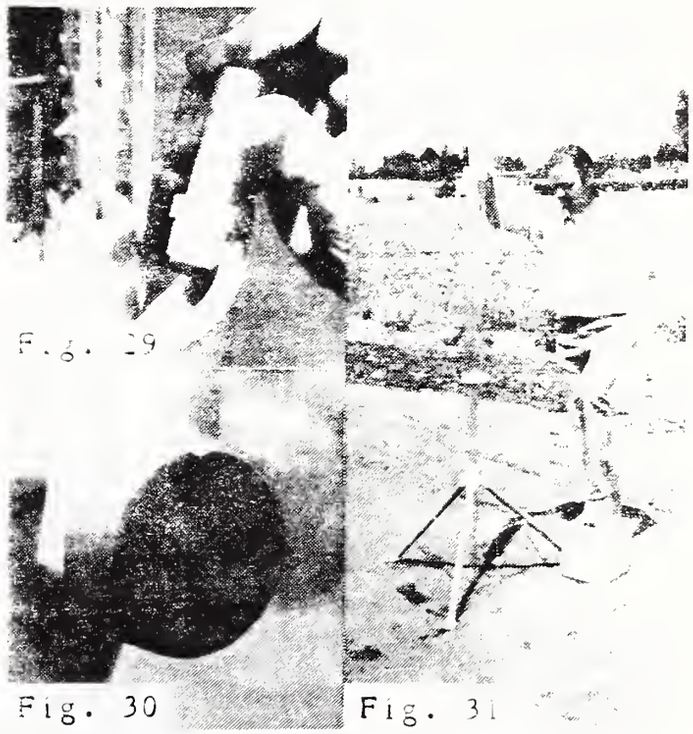


Fig. 29

Fig. 30

Fig. 31

PLACEMENT OF PERMEAMETER

Simply center the Tripod over the well hole and slowly lower the Permeameter so that the Support Tube enters into the well hole, being careful not to knock debris off the sides of the well into the hole bottom, see Fig. 32. Flexibility in the Tripod Base allows the angle of the Tripod Legs to be adjusted to accommodate variation in slope of the land. The Tripod is used to support the permeameter in wells down to approximately 38 cm (15 inches) in depth. The tripod chain can be loosened as necessary to allow the Tripod Legs to flex.

For use in wells deeper than 38 cm (15 inches), the Tripod Bushing alone provides the functions of centering and stabilizing the permeameter. Lift the Tripod Bushing from its position in the permeameter base. The entire permeameter can then be lifted clear of the Tripod. Lower the permeameter slowly into the well hole until the Water Outlet Tip rests on the well bottom. Again, care should be taken to avoid knocking debris from the sides of the well into the bottom. Once the permeameter is in place, center and stabilize it by lowering the Tripod Bushing into top of the well hole. Secure the Tripod Bushing with a firm push into the soil, as shown in Fig. 33.

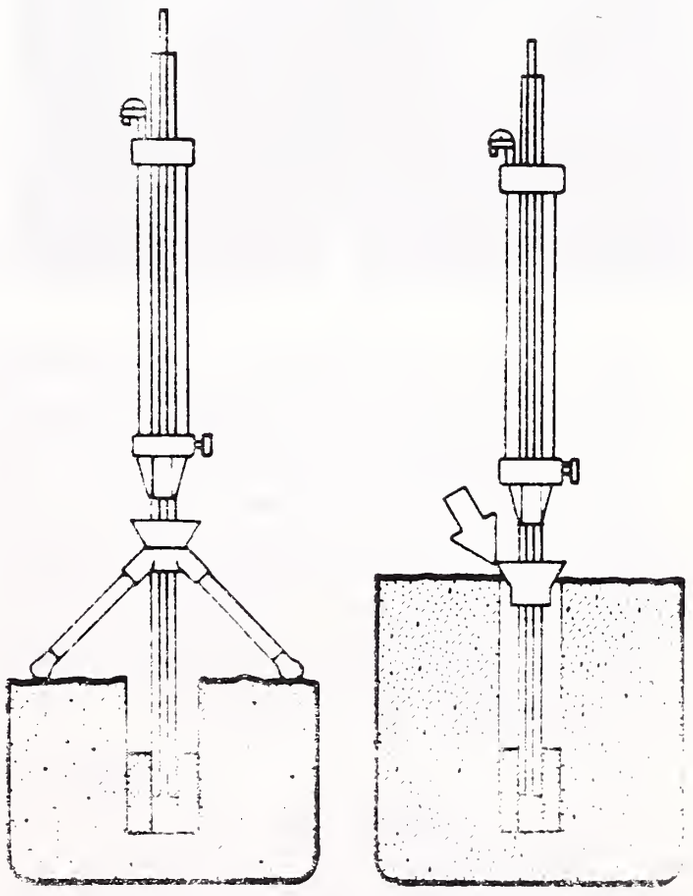


Fig. 32

Fig. 33

MAKING A READING

Make certain that adequate water is available to perform the number of measurements required for your particular field investigation. After the permeameter has been assembled, filled, and placed in the prepared well hole, the following standardized procedure should be followed for making measurements.

STEP 1 - Permeameter Settings

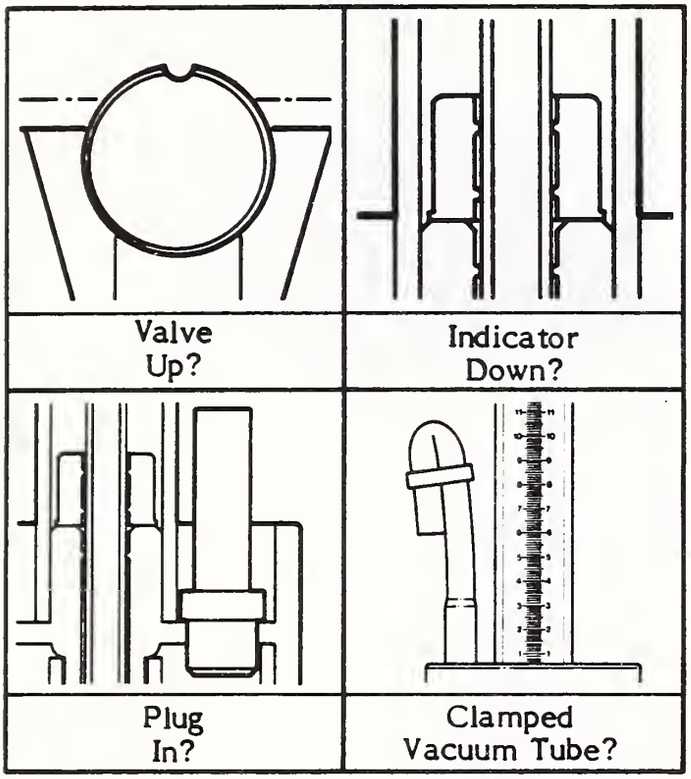


Fig. 34

Verify that both Reservoirs are connected. The Reservoirs are connected when the notch on the Reservoir Valve is pointing up. It is also important to verify that the Well Height Indicator and the Well Head Scale are seated down flush against the top of the Reservoir Cap. This is described under "Permeameter Assembly", page 9. In addition, the Fill Plug must be fully seated against the Reservoir Cap, and the Vacuum Tube closed off with the Clamping Ring, see Fig. 34.

STEP 2 - Establish 5 cm Well Head Height (H_1)

Slowly raise the Air Inlet Tip, see Fig. 35, by grasping the Upper Air Tube, to establish the first well head height. Raising the Air Tube too quickly can cause turbulence and erosion in the well and a potential surging effect that could cause the well to temporarily overfill.

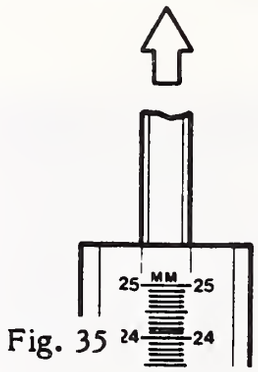


Fig. 35

Fig. 36

Raise the Air Tube until a well height of 5 cm is established, as indicated by reading the lower edge of the Well Height Indicator against the Well Head Scale, see Fig. 36.

STEP 3 - Select Appropriate Reservoir

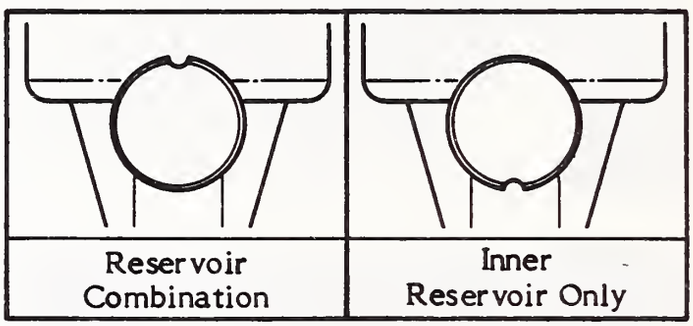


Fig. 37

Observe the rate of fall of the water level in the reservoir. If it is too slow to easily distinquish the drop in level between consecutive readings, usually a 2 minute interval, then turn the Reservoir Valve so that the notch is pointing down in the 6 O'clock position. Water will then be supplied only from the small diameter inner reservoir which will result in a much greater drop in water level between readings, see Fig. 37.

ONCE THE APPROPRIATE RESERVOIR IS SELECTED DO NOT CHANGE THE RESERVOIR VALVE.

STEP 4 - Measure Permeameter Outflow, First Well Height

Outflow of water from the permeameter into the soil is indicated by the rate of fall of water in the reservoir.

Note and record the water level in the selected reservoir as read against the scale stamped on the Inner Reservoir Tube. Read-

ings should be made at regular time intervals. As a standardized procedure, two minute intervals are suggested. The difference of readings at consecutive intervals, divided by the time interval, equals the rate of fall of water, R, in the reservoir.

When investigating clay soils, situations may arise where the rate of fall of water is so slow that a two minute time interval may not be long enough to detect a measurable change in the water level in the reservoir. In these cases, a longer time interval is more appropriate. Increase the time interval as needed for measurement of the rate of fall of water in the reservoir, perhaps 15 minute intervals, or longer.

On the other hand, in situations where the rate of fall of water is very fast, such as in sandy soils, a time interval as short as 15 seconds may be more appropriate. Make the calculation for R based on the actual time interval selected.

For example, at time = 0 minutes, assume the level of water in the reservoir is at 5.9 cm as read on the Reservoir Scale. After the elapse of the first time interval, time = 2 minutes, the level of water is at 6.5 cm. The rate of fall, R, of water in the reservoir, is calculated as the change in the level of the water, in centimeters, divided by the time interval for the change, expressed in seconds.

The calculation is shown below:

R = (6.5 cm - 5.9cm)/(2 min) (60 sec/min)
R = (.6 cm)/(120 sec)
R = .005 cm/sec

Continue monitoring the rate of fall of water in the reservoir until the rate of fall does not significantly change in three consecutive time intervals. This rate is called $\overline{R}_1$ and is defined as the "steady state rate of fall" of water in the reservoir at H_1. H_1 is the first well height established and is always 5 cm in the standardized procedure. See Flowchart on page 6.

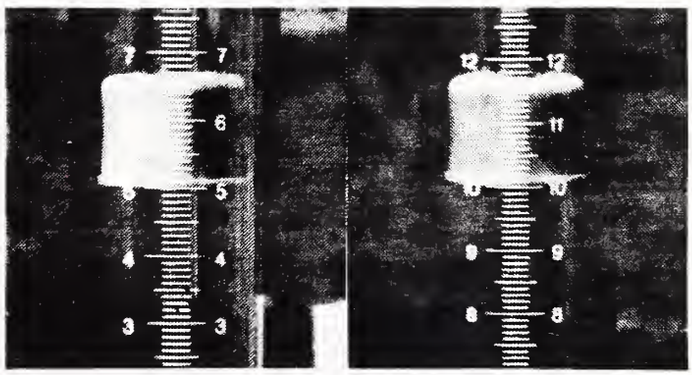
In very heavy clay soils, where the hydraulic conductivity is extremely low, the Permeameter can be left in place for a long period of time while other tasks are being attended to. Under these circumstances periodic readings can be made at convenient intervals until the rate of fall reaches a stable value. A stable value is achieved when essentially the same rate of fall is obtained in consecutive time intervals. The rate of fall for each time interval is determined by dividing the change in water height in the reservoir in centimeters by the time interval in seconds. The "steady state rate of fall" in this situation is simply the stable value obtained.

After completing the outflow measurements, DO NOT DISTURB the Permeameter in any manner and proceed immediately to Step 5.

STEP 5 - Establish 10 cm Well Head Height H_2

Slowly raise the Air Inlet Tip by grasping the Upper Air Tube, to establish the second well head height of 10 cm.

Raise the Air Tube until a well height of 10 cm is established, as indicated by reading the lower edge of the Well Height Indicator against the Well Head Scale, see Fig. 38.



5 cm to 10 cm

Fig. 38

STEP 6 - Measure Permeameter Outflow, Second Well Height

As in STEP 4, monitor the rate of fall of water, R, in the reservoir until a stable value of R is measured. This rate is called $\overline{R}_2$ and is defined as the "steady state rate of fall" of water in the reservoir at H_2. H_2 is the second well height established and is always 10 cm in the standardized procedure.

The field-saturated hydraulic conductivity K_{fs} and matric flux potential ϕ_m can now be readily calculated using the equations on page 14, under standardized calculations. When the reservoir combination has been selected to supply water to the well, use equations 1 and 2 on page 14, to calculate

K_{fs} and ϕ_m . When the Inner Reservoir only has been selected, use equations 3 and 4 on page 14 to calculate K_{fs} and ϕ_m . It is essential to use the correct equations to make the calculations because each equation incorporates a cell constant which corresponds to the cross-sectional area of the reservoir selected.

STANDARDIZED CALCULATIONS

HYDRAULIC CONDUCTIVITY AND MATRIC FLUX POTENTIAL

The following formulas are used to determine hydraulic conductivity K_{fs} and matric flux potential ϕ_m when following the standardized procedure in this manual.

When using both reservoirs:

Equation 1:

$$K_{fs} = (.0041)(X)(\overline{R}_2) - (.0054)(X)(\overline{R}_1)$$

Equation 2:

$$\phi_m = (.0572)(X)(\overline{R}_1) - (.0237)(X)(\overline{R}_2)$$

When using the Inner Reservoir:

Equation 3:

$$K_{fs} = (.0041)(Y)(\overline{R}_2) - (.0054)(Y)(\overline{R}_2)$$

Equation 4:

$$\phi_m = (.0572)(Y)(\overline{R}_1) - (.0237)(X)(\overline{R}_2)$$

X = Reservoir constant used when the reservoir combination is selected.

Y = Reservoir constant used when the inner reservoir only is selected.

NOTE:
The reservoir constants are stamped on the notched Reservoir Valve of the permeameter.

SORPTIVITY

When the volumetric water content of the soil can be measured or estimated with reasonable accuracy, soil sorptivity S can be calculated as follows:

$$S = \sqrt{2(\Delta\Theta)\phi_m}$$

Where $\Delta\Theta = \Theta_{fs} - \Theta_i$

Θ_i = initial volumetric water content
Θ_{fs} = field-saturated volumetric water content

ALPHA CONSTANT AND THE CONDUCTIVITY - PRESSURE HEAD RELATIONSHIP

Alpha is a constant which is dependent on the porous properties of soil. It is calculated as follows:

$$\alpha = K_{fs}/\phi_m$$

The Hydraulic Conductivity/Pressure-Head relationship, $K(\varphi)$ describes the change in K with soil suction. Generally, as soil suction increases, hydraulic conductivity decreases exponentially. For any soil suction (as measured in cm of water), the hydraulic conductivity can be predicted by the following equation.

$$K = K_{fs}[e^{(\alpha)(\varphi)}]$$

Where,

φ = soil water suction in cm of water
e = 2.71828 (base of natural logarithm)

NEGATIVE RESULTS

The results of measurements with the Guelph Permeameter can indicate soil heterogeneity. When a negative K_{fs} or ϕ_m value is calculated, it is indicative of the presence of a hydrologic discontinuity, typically caused by soil stratification or the presence of rodent and/or root holes. This underlines the value of a profile description. When a negative value for K_{fs} or ϕ_m is obtained, it indicates that further measurements are needed to account for the degree and kind of soil heterogeneity.

ACQUAINT YOURSELF WITH THE PARTS

The Guelph Permeameter is broken down into four basic sections for easy storage and transportability. These four sections are:

- Tripod Assembly
- Support Tube and Lower Air Tube fittings
- Reservoir assembly
- Well Head Scale and Upper Air Tube fittings

In addition, auxiliary tools are included to provide a complete, self-contained kit that can be easily transported as luggage for making field measurements in virtually all soils.

TRIPOD ASSEMBLY

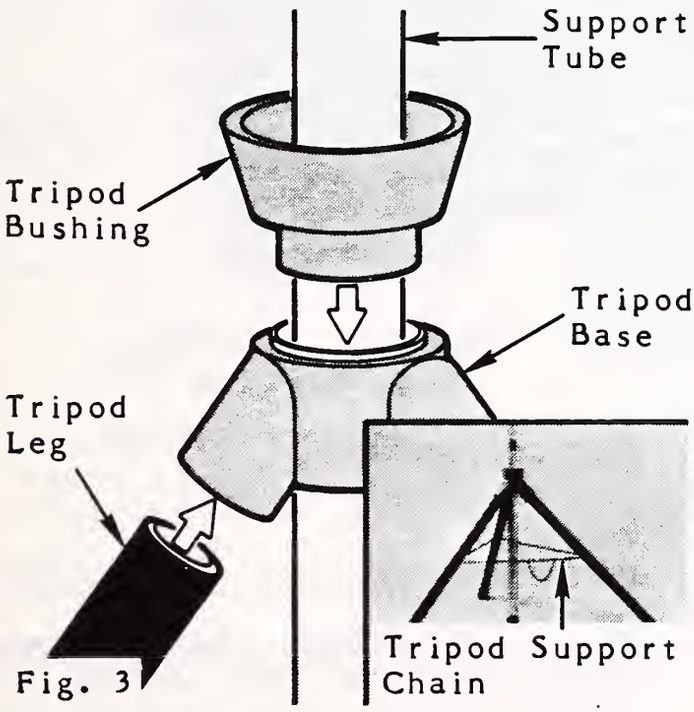


Fig. 3

The Tripod Assembly consists of a Tripod Base with moveable Tripod Bushing and 3 detachable Tripod Legs complete with end tips. The flexible Tripod Base has 3 leg sockets into which the Tripod Legs are inserted, see Fig. 3. After assembly and placement, the Tripod is secured using the Tripod Support Chain.

SUPPORT TUBE AND LOWER AIR TUBE FITTINGS

These are the fittings which conduct water from the reservoir assembly into the well hole and provide the means for establishing and maintaining a constant head in the well hole.

The Support Tube supports the reservoir assembly over the well hole and conducts water from the Reservoir to the Water Outlet Tip.

The Water Outlet Tip serves as a base for the permeameter and disperses the energy of the outflowing water through the ribbed vents at the bottom of the tip to minimize erosion of soil in the well hole. The Air Tip Seating Washer rests on the inside step of the Water Outlet Tip and is the seat for the Air Inlet Tip. When the Air Inlet Tip is fully seated against the Air Tip Seating Washer, air cannot move up the Support Tube and there is no flow of water out of the reservoir.

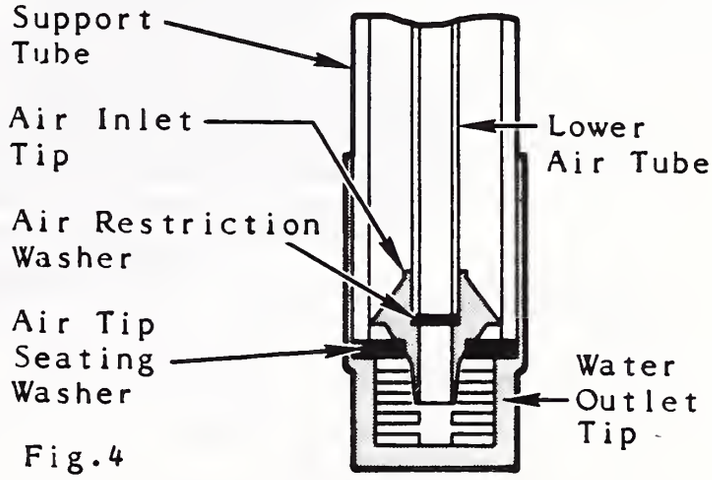


Fig.4

The Air Inlet Tip is connected to the bottom of the Lower Air Tube and is used to regulate the well head height. The Air Restriction Washer is located inside the Air Inlet Tip and regulates air flow to provide a constant, non-fluctuating head in the well, see Fig. 4. The Guelph Permeameter employs the Mariotte principle to maintain a constant well head and this is described in further detail in the "Theory" section on page 22.

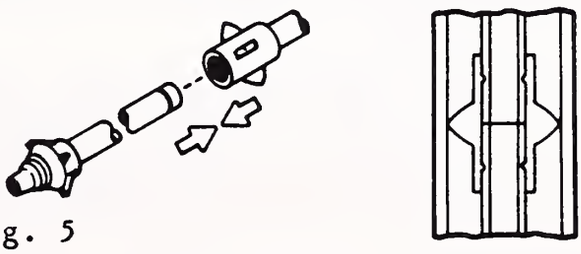


Fig. 5

The Air Tube Coupling joins the Lower Air Tube to the Middle Air Tube and is designed with stabilizing fins to center and prevent bowing of the air tube inside the Support Tube, see Fig. 5.

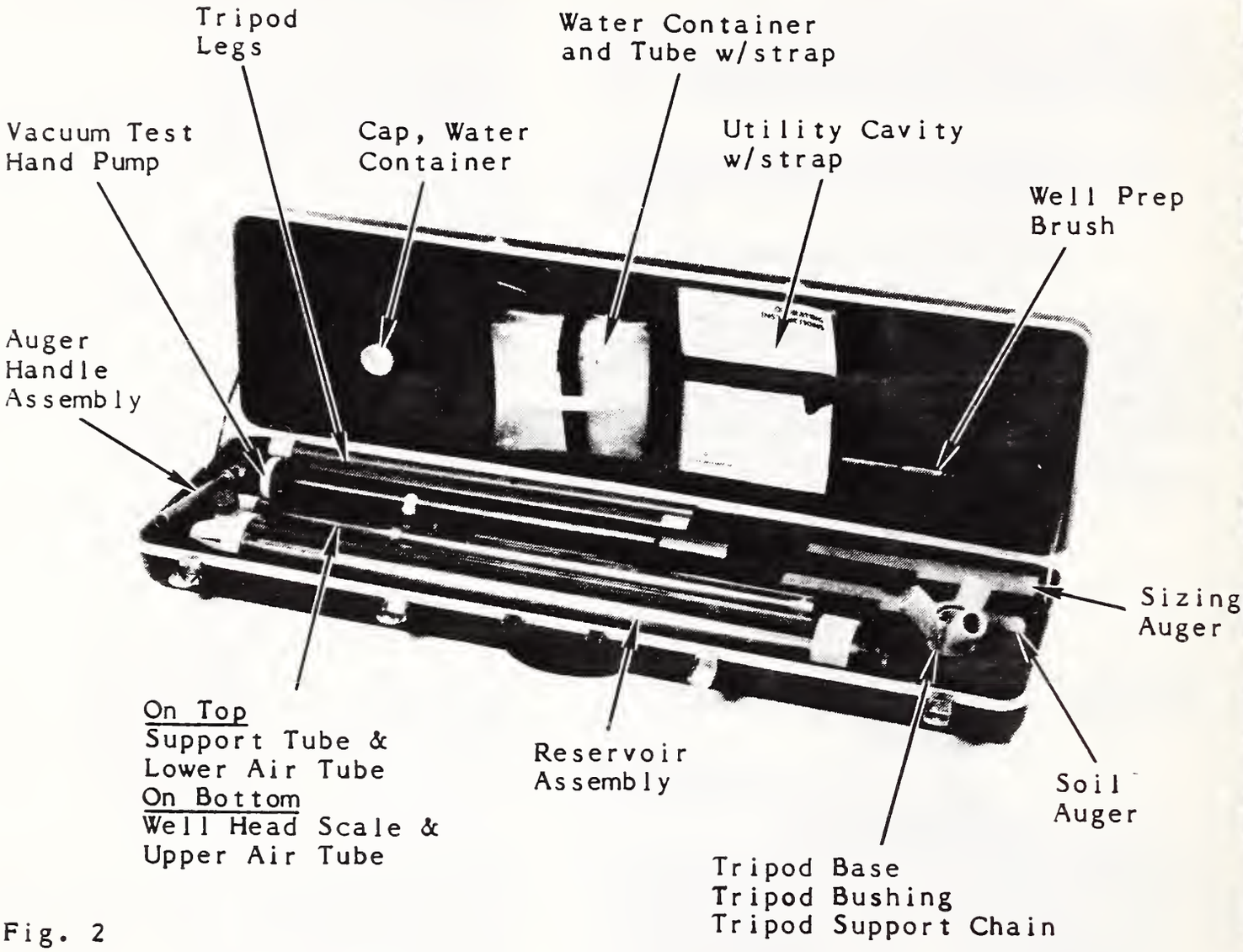


Fig. 2

The Model 2800K1 Guelph Permeameter is a constant-head device which operates on the Mariotte siphon principle and provides a quick and simple method for simultaneously determining field saturated hydraulic conductivity, matric flux potential and soil sorptivity in the field.

Using the Guelph Permeameter, measurements can usually be made and results calculated in less than an hour by following the step-by-step standardized procedure and calculations which are detailed in this instruction booklet.

The Guelph Permeameter comes as a kit and can be broken down into several segments for convenient storage in its easily transportable carrying case. Component parts of the Guelph Permeameter assembly are made of high impact polycarbonate or specially molded elastomers to withstand rugged field use and assure long lasting performance.

UNPACKING

The Model No. 2800K1 Guelph Permeameter shipped to you has been thoroughly tested before shipment. When packed, it was in perfect order. Unpack with care being sure to remove all packing material. Follow the instructions carefully in order to assure long trouble-free service.

NOTE: ANY DAMAGE FOUND UPON RECEIPT, SHOULD BE REPORTED IMMEDIATELY TO THE TRANSPORT CARRIER FOR CLAIM. IT IS IMPORTANT THAT YOU SAVE THE SHIPPING CONTAINER AND ALL EVIDENCE TO SUPPORT YOUR CLAIM.

Be sure to read all Operating Instructions thoroughly before operating the unit.

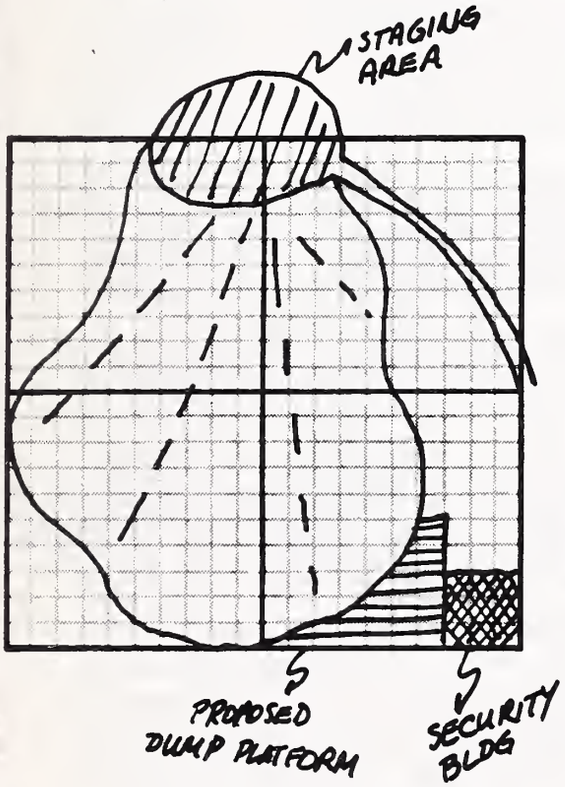
GP FIELD DATA SHEET — SECTION 1: SITE INFORMATION

Date 4/1/86 Investigator G. Howell

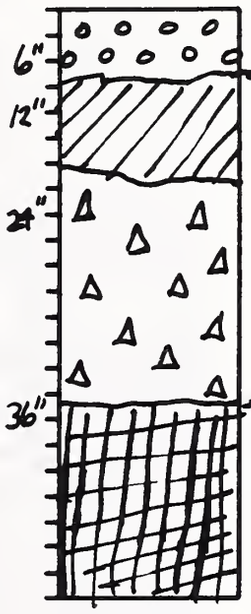
Site Location SITE #24A, BAKER LANDFILL, 2 mi. east of BAKER

Dominant Soil Type(s) BAKER LOAM

Site Map: NW¼, Sec. 14, T2IE, R42W



Soil Profile Description (horizon depth, texture, structure, color, etc.):



Presence of special soil conditions (mottling, water table depth, hardpan, induration, compacted layers, etc.):

PRESENCE OF MOTTLING AT 14-36" INDICATES SEASONALLY FLUCTUATING WATER TABLE; PRESENCE OF CLAY PAN AT 36"+

Comments and Notes (topography, slope, vegetation, etc.):

(1) WELL DEPTH = 2 ft.

(2) GENTLY ROLLING SLOPE (0-8%); NO VEGETATION (RECENT WILDFIRE)

(3) NOTE PRESENCE OF CLAY PAN AT 3 FT.; EXISTS OVER ENTIRE PROPERTY

GP FIELD DATA SHEET

SECTION 2: STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS

Date 4/1/86 Investigator G. HOWELL

Reservoir Constants: (See label on Permeamter)

Combined Reservoirs X	35.39	cm^2	✓ CHECK RESERVOIR USED
Inner Reservoir Y	2.14	cm^2	

Depth of Well Hole 2 ft.

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_1, (CM/MIN)
1	0	—	5.2	—	—
2	2	2	5.9	.7	.35
3	4	2	6.5	.6	.3
4	6	2	7.1	.6	.3
5	8	2	7.7	.6	.3
6	10	2	8.3	.6	.3
7	12	2	9.0	.7	.35
8	14	2	9.6	.6	.3
9	16	2	10.1	.5	.25
10	18	2	10.7	.6	.3
11	20	2	11.3	.6	.3
12	22	2	11.9	.6	.3
13	24	2	12.5	.6	.3

$\bar{R}_1$

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_2, (CM/MIN)
1	0	—	14.8	—	—
2	1	1	15.3	.5	.5
3	2	1	15.9	.6	.5
4	3	1	16.4	.5	.6
5	4	1	16.9	.5	.5
6	5	1	17.4	.5	.5
7	6	1	17.9	.5	.5
8	7	1	18.4	.5	.5
9	8	1	18.9	.5	.5

$\bar{R}_2$

CALCULATIONS

$\bar{R}$, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\bar{R}_1 = (\underset{R_1}{.3})/60 = .005$ cm/sec

For the 2nd Set of Readings $\bar{R}_2 = (\underset{R_2}{.5})/60 = .0083$ cm/sec

K_{fs} FIELD SATURATED HYDRAULIC CONDUCTIVITY $= [(.0041)(\underset{\text{RESERVOIR CONSTANT}}{35.39})(\underset{\bar{R}_2\text{-STEADY STATE RATE OF FLOW}}{.0083})] - [(.0054)(\underset{\text{RESERVOIR CONSTANT}}{35.39})(\underset{\bar{R}_1\text{-STEADY STATE RATE OF FLOW}}{.005})] = 2.5 \times 10^{-4}$ cm/sec

ϕ_m MATRIC FLUX POTENTIAL $= [(.0572)(\underset{\text{RESERVOIR CONSTANT}}{35.39})(\underset{\bar{R}_1\text{ STEADY STATE RATE OF FLOW}}{.005})] - [(.0237)(\underset{\text{RESERVOIR CONSTANT}}{35.39})(\underset{\bar{R}_2\text{ STEADY STATE RATE OF FLOW}}{.0083})] = 3.2 \times 10^{-3}$ cm^2/sec

α ALPHA PARAMETER $= (\underset{K_{fs}}{2.5 \times 10^{-4}}) / (\underset{\phi_m}{3.2 \times 10^{-3}}) = .078$ cm^{-1}

$\Delta\theta$ DELTA THETA $= (\underset{\theta_s\text{, FIELD SATURATED WATER CONTENT OF SOIL, IN CM}^3\text{/CM}^3}{.50}) - (\underset{\theta_i\text{, AMBIENT WATER CONTENT OF SOIL, IN CM}^3\text{/CM}^3}{.35}) = .15$ cm^3/cm^3

ESTIMATED	✓
MEASURED	

CHECK ONE

S SORPTIVITY $= \sqrt{2(\underset{\Delta\theta}{.15})(\underset{\phi_m}{3.2 \times 10^{-3}})} = .031$ cm $sec^{-1/2}$

MAKING A READING IN DEEP WELLS

Extension tubes and couplings are available for the Support Tube, Air Tube, and Auger for use in making measurements at deeper depths. The Guelph Permeameter can theoretically be used to considerable depths below the surface level, approximately 6 meters (20 ft), when extension tubes are utilized. The procedure is essentially the same as that for use without extension tubes. Some notes are important regarding preparations for making a measurement in deep well holes.

On very deep well holes, it may be desirable to place Extension Tubes and Air Tubes down the well hole before connecting them to the fitting at the base of the Reservoir.

The procedure for adding Air Tubes and Support Tube Extensions is illustrated in Fig. 39.

Connect the first Air Tube Extension, using an Air Tube Coupling, to the Lower Air Tube. Slide the coupled Air Tube into the Support Tube and make sure the Air Inlet Tip is seated in the Air Tip Seat. Slide Support Tube Extension with connected Support Tube Coupling over the Air Tube and couple the Support Tubes. Add additional tubing in the same fashion until sufficient for the desired depth, adding Air Tube Extensions first and then Support Tube Extensions.

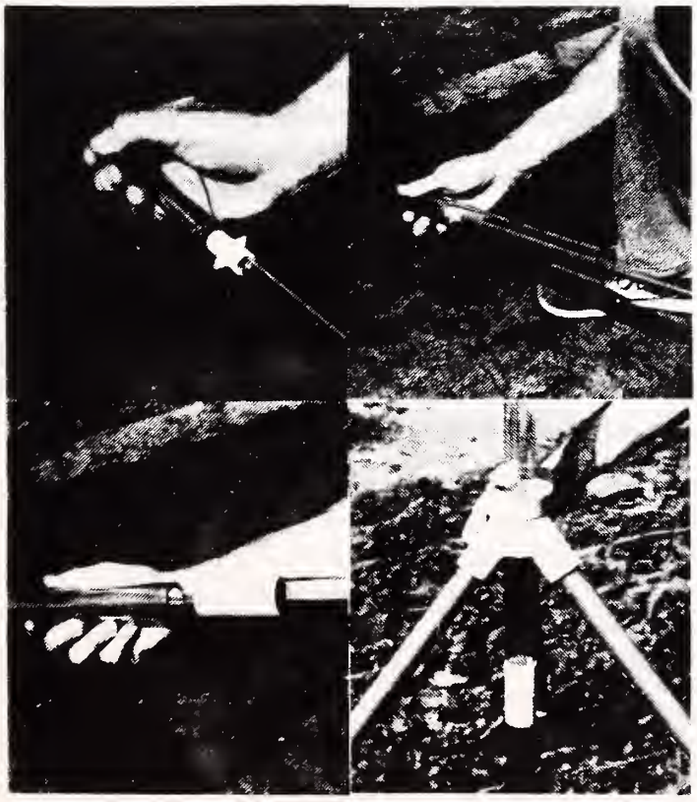


Fig. 39

Slide the Tripod, with Tripod Bushing in place, over the last Support Tube Extension added. If the Reservoir Base will be closer than 38 cm (15 inches) to the soil surface, omit the Tripod and use the Tripod Bushing alone to center and stabilize the permeameter in the well hole. Use of the Tripod Bushing alone is described more completely under "Placement of Permeameter", page 11.

Fill the reservoir as described under "Water Filling" on Page 11. On deep measurements an initial vacuum should be created in the reservoir before setting the well height. See section below "Making a Reading With Limited Water Supplies" for details.

After the permeameter is placed in the well hole and the reservoir filled, follow the procedure for "Making a Reading", as described on page 12.

MAKING A READING WITH LIMITED WATER SUPPLIES

When sufficient water is not available to completely fill the permeameter, readings can still be made, but there are additional procedures that must be followed in order to do so.

To prevent overfilling of water into the well when establishing the well head, and insure proper operation, an initial vacuum must be created in the air space above the water in the reservoir. After making sure that the Air Inlet Tip is fully seated, remove the Clamping Ring and attach the Vacuum Hand Pump to the Vacuum Tube located in the

Fig. 40

Reservoir Cap. Pull a vacuum of 20 centibars, bend the Vacuum Tube over with the Hand Pump still attached, and close it off with the Clamping Ring, see Fig. 40. Disconnect the Vacuum Hand Pump and continue with the procedure as described in

STEP 2, "Establish 5 cm Well Head Height H_1 ," page 12.

When using the Permeameter in deep applications an additional initial vacuum of about 10 centibars must be applied for each additional 80 cm long standard Model 2800K2 Extension Kit used.

USE AND APPLICATION

The Guelph Permeameter can be used anywhere a hole can be augered in soil. This instruction booklet presents a standardized method for determining field-saturated hydraulic conductivity, matric flux potential, and soil sorptivity.

Because of the practical improvements incorporated in the operation of the Guelph Permeameter and the advanced analysis the theory provides, it is ideally suited for applications involving the design and monitoring of;

- Irrigation Systems
- Drainage Systems
- Canals
- Reservoirs
- Sanitary Landfills
- Land Treatment Facilities
- Tailings Areas
- Hazardous Waste Storage Sites
- Septic Tank Systems
- Soil and Hydrologic Studies and Surveys

DEPTH PROFILING

It is almost always the case that the water transmission properties of soil varies with depth. The Guelph Permeameter can be used to investigate changes in the hydraulic properties of soils with depth. When using the permeameter for this purpose, it is recommended that the investigator auger a hole at shallow depth first. After making a measurement at the shallow depth, the well hole can be extended by further augering to successive depths and making the respective measurements, see Fig. 41.

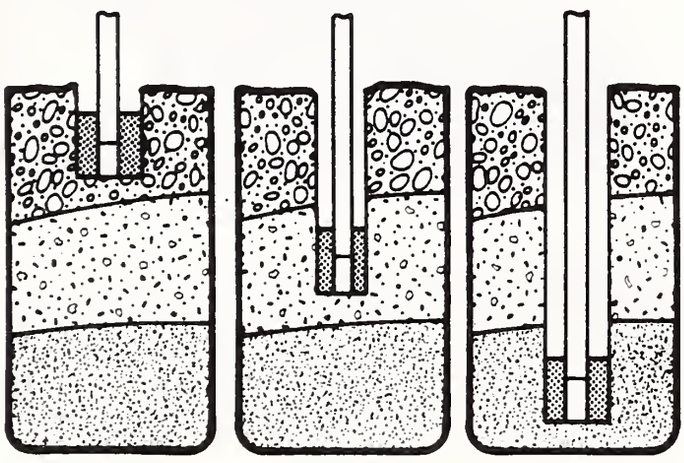


Fig. 41

HETEROGENEOUS SOILS

Soils typically have three dimensional heterogeneity. The Guelph Permeameter method yields essentially a "point" measurement. The size of land under investigation, degree of soil heterogeneity, soil type, and kind of application will dictate the number of measurements needed to adequately characterize a given area and depth of soil.

A soil profile description and soil survey report will greatly enhance the value and understanding of data obtained with the Guelph Permeameter.

Because of the ease and simplicity of the Guelph Permeameter and its depth profiling capability, it is a very useful method for understanding the three dimensional distributions of the water transmission properties of soils.

EXPERIMENTAL WORK

For experimental purposes, the diameter of the well hole and height of well heads used can be varied. The generalized calculations are included in the section entitled "Generalized Calculations" on page 23.

The Guelph Permeameter can be used for a range of research objectives including studying the effects of viscosity on K_{fs} spatial variability studies, and field equipment comparison studies.

HELPFUL HINTS IN NORMAL USE

The reservoir combination is used in soils of moderate to high permeability. Soils that fit into this category typically have some degree of structure, medium to coarse texture, and little to no cementation or compaction. The Inner Reservoir only is used for work in soils of low permeability. Soils that fit into this category are typically fine textured, structureless, or are significantly cemented or compacted.

It is helpful, although not mandatory, to make readings of R, the rate of fall of water in the reservoir, at the specified two minute time interval, as described in the standardized procedure. By using a specified time interval, it is very easy to determine when R, the steady state rate of fall of water in the reservoir, is reached without calculation in the field.

For shallow use (wells less than 30 inches deep), it is recommended that the reservoir be filled before the permeameter is placed in the well hole. This enables the operator to verify proper functioning of permeameter fittings and insure that the Air Inlet Tip is fully seated in the Air Tip Seat. The possibility of an unexpected water spill into the hole is also reduced when the reservoir is filled away from the hole. When an operator is making measurements in deep wells, it may be necessary to fill the reservoirs after the permeameter has been placed in the well hole. Care should be taken to insure that all Air Tube and Support Tube Couplings are tightly fitted to their respective extensions and that the Air Inlet Tip is fully seated in the Air Tip Seat.

Familiarize yourself with the setup, operation, procedures theory, and calculations before going to the field with the Guelph Permeameter. Doing so will facilitate accurate measurements and interpretation of results.

The moveable molded plastic parts of the permeameter, may exhibit a slight seizing or sticking effect. It is this characteristic of the plastics that suits them well to the airtight/watertight seals needed on the Guelph Permeameter. Fittings, such as the Reservoir Valve, may stick a very little bit when first moved. However, they will then move freely.

The Soil Auger included with the Guelph Permeameter is designed for general use. Accessory auger bits are available for use in specialized situations. Model No. 231 Mud Auger has an open bucket to prevent clogging and to increase the ease of operation in sticky, wet soils. It is useful in wet silts and heavy clay soils. Model 232 Sand Auger cutting bits have been specifically shaped for cutting into dry, sandy soils without allowing the contents of the bucket to escape and refill the augered hole. Ordering information is located in the back of this booklet, under "Accessory Items".

GENERAL CARE AND MAINTENANCE

A general cleanup is recommended as soon as practical after each field use to maintain the transparency of plastic tubes and to prevent clogging, scratching and fouling of permeameter fittings by soil grit. Wipe off with a cloth or rinse the permeameter down with clean water to remove soil and grit. Make sure to pay particular attention to small openings where grit can accumulate or soil can dry and cake, such as in the Water Outlet Tip, Air Inlet Tip, Tripod Bushing, and behind the Reservoir Valve. Use a clean, soft cloth to wipe down and dry off the outer surfaces of the permeameter.

Take apart the permeameter for a thorough cleaning when necessary and clean with soap and water. After cleaning with soap, rinse thoroughly with clean water and dry. The various flexible plastic fittings used in the permeameter are all friction fits to the various tubes. No cement or other sealant is used. The fittings can be disconnected by carefully "working" them off with the hands.

The Reservoir Valve fits into the Reservoir Base by means of a ridge-and-groove friction fitting. To remove for cleaning, place your fingers behind the valve, brace against the Reservoir Base, and pull sharply straight out

Fig. 42

as shown in Fig. 42. The Reservoir Valve can be lubricated with vacuum grease or vasoline if it is sticking or seizing excessively.

Clean the carrying case lining regularly to prevent accumulation of soil and grit that can cause scratching of the transparent plastic tubes.

TROUBLE SHOOTING

	PROBLEM	POSSIBLE REASON(S)
1)	Well hole overfills upon initial filling	1) Too much air above the water in the reservoirs at beginning of measurement, Fill Plug is not fully seated, Vacuum Line is not shut off with Clamping Ring
2)	Water leaks at Water Outlet Tip when permeameter is off	2) Air Inlet Tip is not properly seated against Air Tip Seat.
3)	Well Head level falls below that set by Well Head Indicator	3) Air Tube Clogged; inspect Air Restriction Washer.
4)	Well head level rises above that set by Well Head Indicator	4) Too much air above the water in the reservoirs at beginning of measurement. Fill Plug not fully seated, Vacuum Line is not fully shut off with Clamping Ring.
5)	Stable well head level does not correspond with that set by Well Head Indicator	5) Water Outlet Tip is not seated on the bottom of the well hole Well Height Indicator was not fully seated against Reservoir Cap before raising Air Inlet Tip. Well Head Scale was not fully seated against recess in Reservoir Cap before raising Air Inlet Tip.

THEORY

Three of the most important factors governing liquid transmission in unsaturated soils are field-saturated hydraulic conductivity, K_{fs}, matric flux potential, ϕ_m, and sorptivity, S.

Hydraulic conductivity is the measure of the ability of a soil to conduct water under a unit hydraulic potential gradient. K_{fs}, or field-saturated hydraulic conductivity refers to the saturated hydraulic conductivity of soil containing entrapped air. K_{fs} is more appropriate than the truly saturated hydraulic conductivity for vadose (unsaturated) zone investigations because, by definition, positive pressure heads do not persist in unsaturated conditions long enough for entrapped air to dissolve.

Matric Flux Potential, ϕ_m, is the measure of a soil's ability to pull water, by capillary force, through a unit cross sectional area in a unit time.

Sorptivity, S, is the measure of the ability of a soil to absorb a wetting liquid. In general, the greater the value of S, the greater the volume of a wetting liquid that can be absorbed and the more rapidly the liquid is absorbed.

Since Sorptivity is defined in part by Matric Flux Potential, they are essentially two different ways of describing the same phenomenon.

Hydraulic conductivity decreases as the soil water suction increases. This relationship is called the conductivity-pressure head relationship. The Guelph Permeameter is used to determine K_{fs} and ϕ_m for a particular soil. Once the soil water suction is measured, the hydraulic conductivity for that soil at that soil water suction can be readily calculated.

MODE OF OPERATION

The Guelph Permeameter is an in-hole constant-head permeameter, employing the Mariotte Principle. The method involves measuring the steady-state rate of water recharge into unsaturated soil from a cylindrical well hole, in which a constant depth (head) of water is maintained.

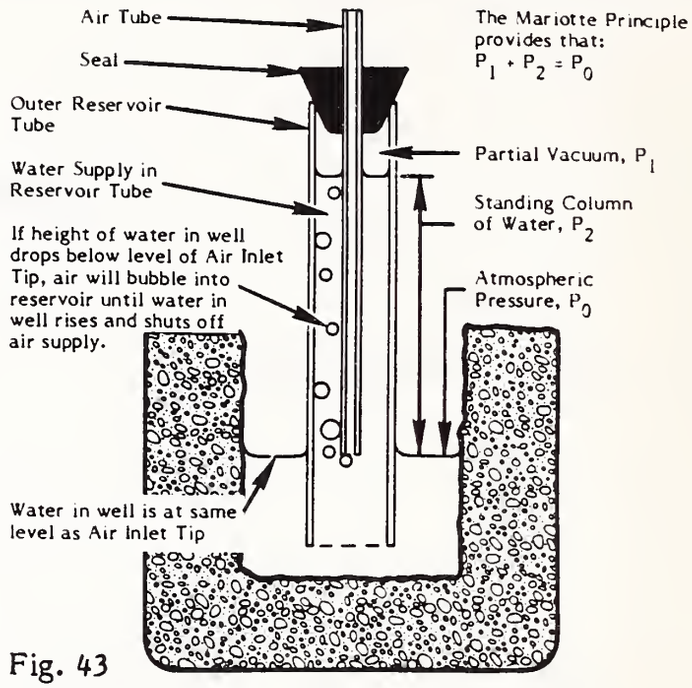

Air Tube
Seal
Outer Reservoir Tube
Water Supply in Reservoir Tube
If height of water in well drops below level of Air Inlet Tip, air will bubble into reservoir until water in well rises and shuts off air supply.
Water in well is at same level as Air Inlet Tip
The Mariotte Principle provides that: $P_1 + P_2 = P_0$
Partial Vacuum, P_1
Standing Column of Water, P_2
Atmospheric Pressure, P_0

Fig. 43

Constant head level in the well hole is established and maintained by regulating the level of the bottom of the Air Tube which is located in the center of the permeameter. As the water level in the reservoir falls, a vacuum is created in the air space above the water. The vacuum can only be relieved when air, which enters at the top of the Air Tube, bubbles out of the Air Inlet Tip and rises to the top of the reservoir. Whenever the water level in the well begins to drop below the Air Inlet Tip, air bubbles emerge from the tip and rise into the reservoir air space. The vacuum is then partially relieved and water from the reservoir replenishes water in the well. The size of opening and geometry of the Air Inlet Tip is designed to control the size of air bubbles in order to prevent the well water level from fluctuating.

When the permeameter is operating, an equilibrium is established. The reduced pressure (vacuum) in the air above the water in the reservoir together with the pressure of the water column extending from the surface of the well to the surface of the water in the reservoir always equals the atmospheric pressure, see Fig. 43.

When a constant well height of water is established in a cored hole in the soil, a "bulb" of saturated soil with specific dimensions is rather quickly established, see Fig. 44. This "bulb" is very stable and its shape depends on the type of soil, the radius of the well and the head of water in the well. The shape of the "bulb" is numerically described

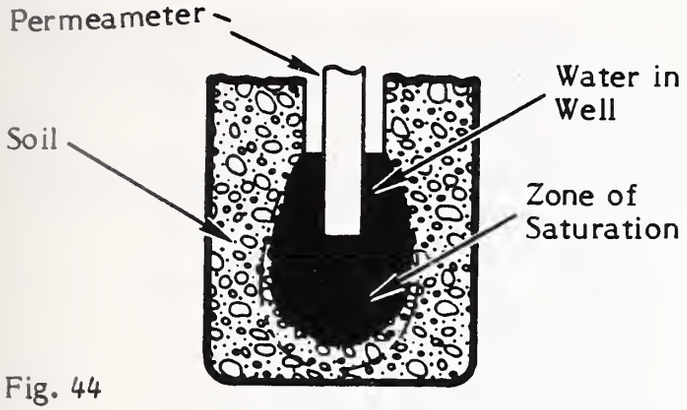


Fig. 44

by the C factor (Reynolds et al., Groundwater Monitoring Review 6:1:84-95, 1986) used in the calculations.

Once the unique "bulb" shape is established, the outflow of water from the well reaches a steady state flow rate which can be measured. The rate of this constant outflow of water, together with the diameter of the well, and height of water in the well can be used to accurately determine the field saturated conductivity, matric flux potential and sorptivity of the soil.

GOVERNING ANALYTIC EQUATIONS

The "Richard's" analysis of steady-state discharge from a cylindrical well in unsaturated soil, as measured by the Guelph Permeameter technique, accounts for all the forces that contribute to three dimensional flow of water into soils: the hydraulic push of water into soil, the gravitational pull of liquid out through the bottom of the well, and the capillary "pull" of water out of the well into the surrounding soil. The "Richard's" analysis is the basis for the calculations used to determine hydraulic conductivity and matric flux potential.

GENERALIZED CALCULATIONS

C-FACTOR

The C Factor is a numerically derived shape factor which is dependent on the well radius a and head H of water in the well. Fig. 45, page 25, shows the curves for three classes of soil.

For experimental applications of the Guelph Permeameter where the radius of the bore hole and well heights are different from those specified in the standard procedure the following calculations apply.

HYDRAULIC CONDUCTIVITY

$$K_{fs} = G_2Q_2 - G_1Q_1$$

where,

$$G_2 = \frac{H_1C_2}{\pi[2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)]}$$

and where,

$$G_1 = G_2\frac{[H_2C_1]}{[H_1C_2]}$$

and where,

$$Q_1 = (X)\overline{R}_1) \text{ or } (Y)(\overline{R}_2)$$

and where

$$Q_2 = (X)(\overline{R}_2) \text{ or } (Y)(\overline{R}_2)$$

Use the cell constant (X) or (Y) appropriate for the reservoir selected.

MATRIC FLUX POTENTIAL

$$\phi_m = J_1Q_1 - J_2Q_2$$

Where,

$$J_1 = \frac{(2H_2^2 + a^2C_2)C_1}{2\pi[2H_1H_2(H_2 - H_1) + a^2(H_1C_2 - H_2C_1)]}$$

and where,

$$J_2 = J_1\frac{[(2H_1^2 + a^2C_1)C_2]}{[(2H_2^2 + a^2C_2)C_1]}$$

C_1, C_2, H_1, H_2 are all defined in the glossary on page 24.

BIBLIOGRAPHY

For further theoretical discussion regarding the use and applicability of the Guelph Permeameter, it is recommended that the user consult the following scientific papers.

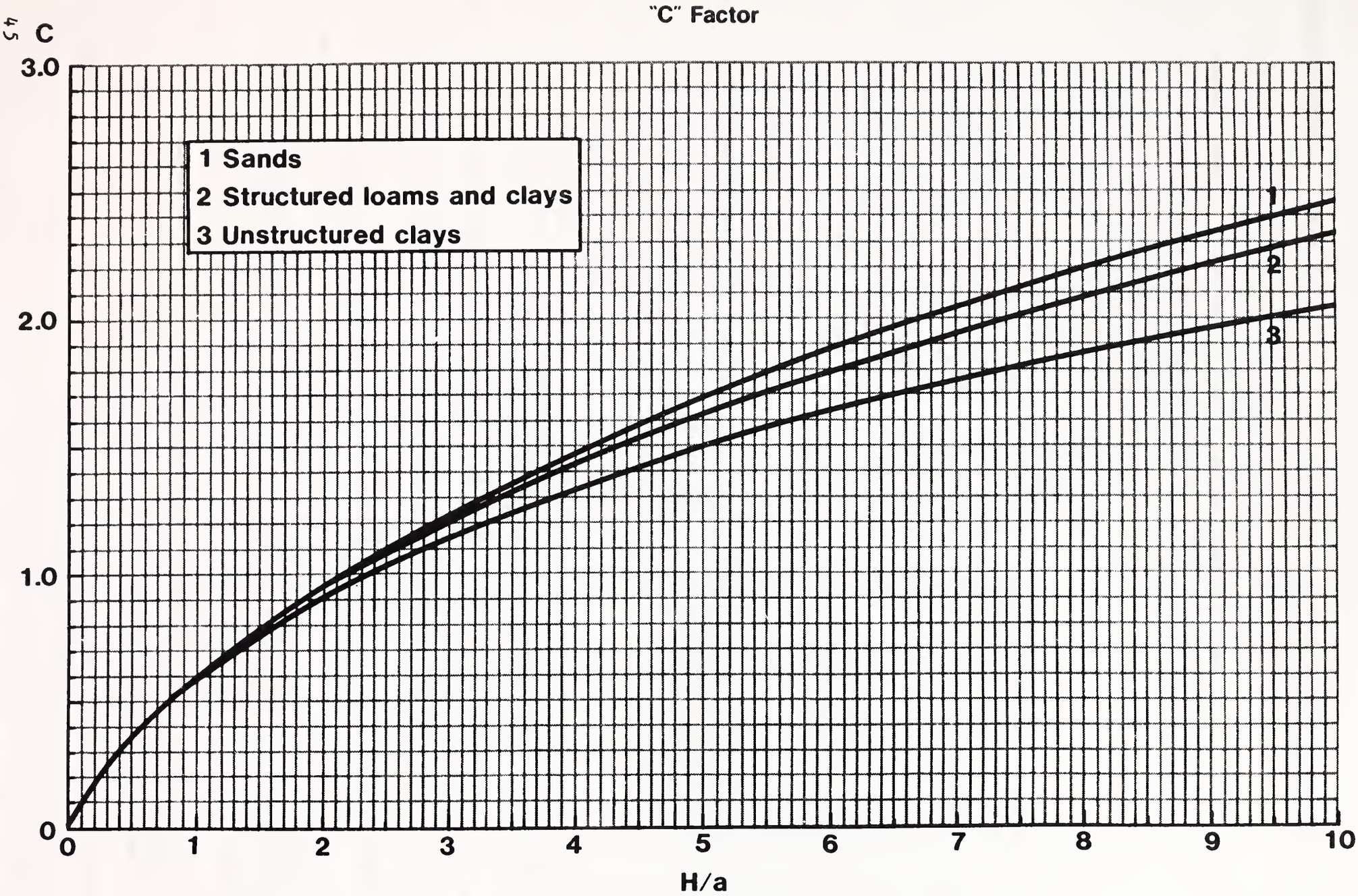
1. Groundwater Monitoring Review, Volume 6, No. 1, Winter 1986, pp. 84-95.

2. Soil Science, Volume 140, No. 4, 1985, pp. 292-302.

GLOSSARY

a	Well radius, in cm.
C	Proportionality factor dependent primarily on the H/a ratio
C_1, C_2	C factors corresponding to H_1/a and H_2/a, respectively
GP	Guelph Permeameter
H_1, H_2	Well height for first and second measurements respectively, in cm.
K	Hydraulic conductivity, in cm/sec.
K_{fs}	Field-saturated hydraulic conductivity (entrapped air present), in cm/sec.
$K(\varphi)$	Hydraulic conductivity/pressure-head relationship for unsaturated flow.
R	Rate of fall of water in the reservoir tube of the permeameter, in cm/min.
$\overline{R}$	Steady-state rate of fall
$\overline{R}_1$, $\overline{R}_2$	Steady-state rate of fall corresponding to H_1 and H_2 respectively, and converted to cm/sec.
S	Sorptivity, in $cm/sec^{1/2}$
α	Alpha Parameter, slope of the curve relating the natural log of K, hydraulic conductivity, to Q, soil water suction, in cm^{-1}.
Θ_i	Ambient volumetric water content in the soil, in cm^3/cm^3.
Θ_{fs}	Field-saturated volumetric water content of the soil (entrapped air present), in cm^3/cm^3.
$\Delta\Theta$	Θ_{fs}-Θ_i, difference between field saturated and ambient volumetric water content of soil, in cm^3/cm^3.
ϕ_m	Matric flux potential, in cm^2/sec.
φ	Soil water suction, measured in cm of water.
X	Reservoir constant, used when reservoir combination is selected, and corresponds to the cross sectional area of the combined reservoirs expressed in cm^2.
Y	Reservoir constant used when the inner reservoir only is selected, expressed in cm^2.

Fig. 45


"C" Factor
C
3.0
2.0
1.0
0
1 Sands
2 Structured loams and clays
3 Unstructured clays
1
2
3
0
1
2
3
4
5
6
7
8
9
10
H/a

GP FIELD DATA SHEET

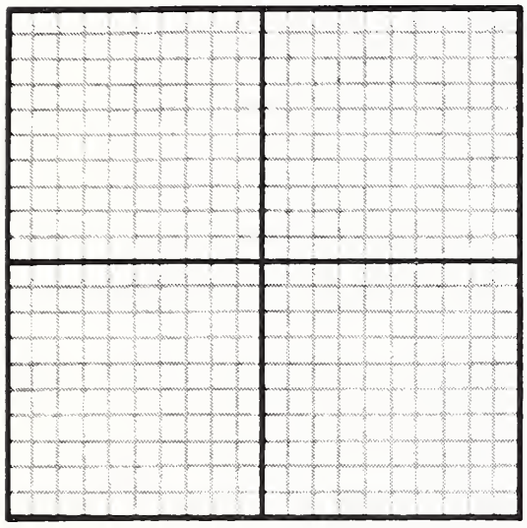
SECTION 1: SITE INFORMATION

Date _____ Investigator _____

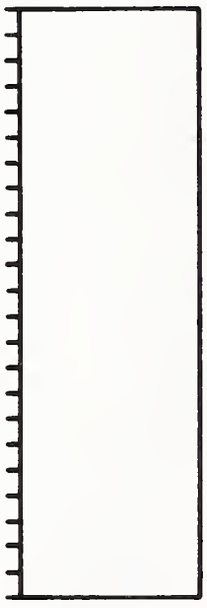
Site Location _____

Dominant Soil Type(s) _____

Site Map:



Soil Profile Description (horizon depth, texture, structure, color, etc.):



Depth

Description

Presence of special soil conditions (mottling, water table depth, hardpan induration, compacted layers, etc.):

Comments and Notes (topography, slope, vegetation, etc.):

GP FIELD DATA SHEET

SECTION 2: STANDARDIZED PROCEDURE FOR PERMEAMETER READINGS AND CALCULATIONS

Date_____Investigator_____

Reservoir Constants: (See label on Permeamter)

Combined Reservoirs X	cm^2	☐ CHECK RESERVOIR USED
Inner Reservoir Y	cm^2	☐

Depth of Well Hole_____

Note: In standardized procedure the radius of the well hole is always 3.0 cm

1st Set of Readings with height of water in well (H_1) set at 5 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_1, (CM/MIN)

2nd Set of Readings with height of water in well (H_2) set at 10 cm

READING NUMBER	TIME	TIME INTERVAL (MIN)	WATER LEVEL IN RESERVOIR, (CM)	WATER LEVEL CHANGE, (CM)	RATE OF WATER LEVEL CHANGE, R_2, (CM/MIN)

CALCULATIONS

$\bar{R}$, the steady state rate of flow, is achieved when R is the same in three consecutive time intervals.

For the 1st Set of Readings $\bar{R}_1$ = (_____ R_1)/60 = _____ cm/sec

For the 2nd Set of Readings $\bar{R}_2$ = (_____ R_2)/60 = _____ cm/sec

K_{fs} = [(.0041)(_____ RESERVOIR CONSTANT)(_____ $\bar{R}_2$ - STEADY STATE RATE OF FLOW)] - [(.0054)(_____ RESERVOIR CONSTANT)(_____ $\bar{R}_1$ - STEADY STATE RATE OF FLOW)] = _____ cm/sec

K_{fs} FIELD SATURATED HYDRAULIC CONDUCTIVITY

ϕ_m = [(.0572)(_____ RESERVOIR CONSTANT)(_____ $\bar{R}_1$ STEADY STATE RATE OF FLOW)] - [(.0237)(_____ RESERVOIR CONSTANT)(_____ $\bar{R}_2$ STEADY STATE RATE OF FLOW)] = _____ cm^2/sec

ϕ_m MATRIC FLUX POTENTIAL

α = (_____ K_{fs})/(_____ ϕ_m) = _____ cm^{-1}

α ALPHA PARAMETER

$\Delta\theta$ = (_____ θ_s, FIELD SATURATED WATER CONTENT OF SOIL, IN CM/CM) - (_____ θ_i, AMBIENT WATER CONTENT OF SOIL, IN CM/CM) = _____ cm^3/cm^3

$\Delta\theta$ DELTA THETA

ESTIMATED	☐
MEASURED	☐

CHECK ONE

S = $\sqrt{2(\text{_____ } \Delta\theta)(\text{_____ } \phi_m)}$ = _____ cm $sec^{-1/2}$

S SORPTIVITY

PARTS LIST

2800-001	Water Outlet Tip
2800-002	Air Inlet Tip
2800-003	Air Restriction Washer
2800-004	Support Tube
2800-005L12	Upper Air Tube
2800-005L21	Lower Air Tube
2800-005L45	Middle Air Tube
2800-006	Air Tube Coupling
2800-007	Reservoir Base
2800-008	Reservoir Valve
2800-009	Outer Reservoir Tube
2800-010	Inner Reservoir Tube
2800-011	Reservoir Cap
2800-012	Well Head Scale
2800-015	Fill Plug
2800-016	Well Height Indicator
2800-017	Air Tip Seating Washer
2801	Tripod Assembly
2801-001	Tripod Base
2801-002	Tripod Leg
2801-003	Tripod Leg Tip
2801-004	Tripod Bushing
2801-005	Tripod Support Chain
2801-006	Tripod Support Sleeve
2802	Sizing Auger
2803	Carrying Case
2804	Well Prep Brush
230D2-100	Soil Auger Cylinder Assembly
230-002	Quick Connect Socket
230-003	Quick Connect Stem
230-100	Handle Assembly
774L24	Pipe Nipple
1900-202	Access Tube
1900-203	Vacuum Tube
2005G2	Vacuum Test Hand Pump
2031G2-001	Clamping Ring, each
2038V3	Water Container (3 gal.)
2038V3-001	Water Container Tube
MSL018	Quick Connect Pin
MSL019	Pin Locking Clip

ACCESSORIES

2800K2	Extension Kit, 80 cm long
Consists of:	
2800-004	Support Tube
2800-005L31	Air Tube Extension
2800-006	Air Tube Coupling
2800-013	Support Tube Coupling
231D2	Mud Auger, 2" Dia.
232D2	Sand Auger, 2" Dia.
233	Handle Extension, 4' includes coupling